Economic and Sustainable development of the Power Sector of Mozambique

By

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Declaration

I, Paxis Marques João Roque, declare that this thesis is my original work, except where stated otherwise. This thesis is being submitted in full fulfilment of the requirements for the degree of Master of Science in Engineering (Sustainable Energy Engineering) at the University of Cape Town. It has not been submitted before for any degree or examination in any other University.

Signature:

Dedication

I dedicate this thesis to my daughter *Kiandra*, who was born in the same year of the admission for this degree.

Acknowledgments

There are a number of people without whom this thesis might not have been written, and to whom I am greatly indebted. Above all, I thank first to God, for giving me health and wellness.

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Abbreviations, acronyms and units

% - Percent

BCI - Banco Comercial e de Investimento

BM - Banco de Moçambique

BPC - Botswana Power Corporation

C - Carbon

C_2H_6 - Ethane

C_3H_6 - Propane

C_4H_{10} - Butane

CARBOMOC E.E - Empresa Estatal de Carvão de Moçambique

CCGT - Combined cycle gas turbine.

CCS - Carbon capture and storage technology

CH_4 - Methane

CHP - Combined heat and power

CIP - Centro de Integridade Pública

CO_2 - Carbon dioxide

CRF – Capital Recover Factor

DoE - Department of Energy

E.P - Empresa Pública

EDM - Electricidade de Moçambique

Ehh - Electrified households

EITI - Extractive Industries Transparency Initiative

ENH - Empresa Nacional de Hidrocarbonetos

ERC - Energy Research Center

ESKOM - Electricity Supply Commission of South Africa

ETD - Electricity transmission and distribution

FOR - Forced outage rate

FUNAE - Fundo Nacional de Energia

GDP - Gross domestic product

GHG - Greenhouse gases

GJ - Gigajoule

GW - Gigawatt

GWh - Gigawatt-hour

H_2O - Water

HCB - Hidroeléctrica de Cahora Bassa

HH - households

Hhh - High consumption households

HVDC - high voltage direct current

IAEA - International Atomic Energy Agency

IDC – Interest during construction

IEA - International Energy Agency

IESE - Instituto de Estudos Sociais e Económicos

IGCC - Integrated gasification combined cycle

IIASA - International Institute for Applied Systems Analysis

IMF - International Monetary Fund

INE - Instituto Nacional de Estatistíca

IPCC - Intergovernmental Panel in Climate Change

IPP - Independent Power Producer

IRENA-– International Renewable Energy Agency

kg - Kilogram

km – Kilometre

kW - Kilowatt

kWh - Kilowatt-hour

LCOE - Levelized costs of electricity

LDC - load duration curve

LEAP - Long Range energy Alternatives Planning System

LEC - Lesotho Electricity Company

Lhh - Low consumption households

m^2 - Meter square

m^3 - Cubic meter

ME - Ministério de Energia

MESSAGE - Model for Energy Supply Strategy Alternatives and their General Environment impacts

MF - Ministério das Finanças

MINED - Ministério da Educação

MIREM - Ministério dos Recursos Minerais

MISAU - Ministerio da Saúde

MITUR - Ministério do Turismo

MJ - Mega Joule

MOTRACO - Mozambique Transmission Company

MOZAL - Mozambique Aluminium Smelter

MPD - Ministerio de Planificaçao e Desenvolvimento

MT - Meticais

MW - Megawatt

MWh - Megawatt-hour

NamPower - Namibia Power Company

NO_x - Nitrogen dioxide

O_2 - Oxygen

ºC - Degree Celsius

OECD - Organisation for Economic Co-operation and Development;

PH - Period hours

POR - Planned outage rate

PP -Power plant

PPI- Plano perspectivo económico

PRE - Programa de reabilitação económica

PV - Solar photovoltaic

SADC - Southern Africa Development Community

SAPP - Southern African Power Pool Plan

SEB – Swaziland Electricity Board

SH – Service hours

SO_x – Sulphur dioxide

SPI - Sasol Petroleum International

SSA - South Africa Statistics

TCF – Trillion cubic feet

TWh – Terawatt-hour

UNDP - United Nations Development Program

UNFCCC - United Nations Framework Convention on Climate Change

USD - United State Dollar

ZESA - Zimbabwe Electricity Supply Authority

Abstract

Mozambique has a vast potential of energy resources which are little exploited, particularly in the power sector. Mozambique's diverse energy resource includes hydropower, natural gas, coal, biomass, solar and wind. Despite this, the country still faces constraints in increasing the level of access to energy. Therefore, the sustainable use of energy resources and the expansion and provision of reliable energy services for all districts is central to addressing many issues related with the development of the country.

According to the Mozambican power utility, "*Electricidade de Moçambique"* (EDM), practically 97% of Mozambique's electricity is generated from hydropower, with total installed capacity of 2179 Megawatts but due the existence of large reserves of coal and gas, the country is also intending to generate 1100 Megawatt from coal, 1790 Megawatt from gas and to increase the generation from hydro. However, before choosing those options regarding energy resources usage, it is important to assess the sustainability of the options from both socio-economic and environmental perspectives.

Policies must wisely track reliable and affordable modern energy supplies and reduce the negative environmental impacts related to energy production and use and capital investments in equipment and energy infrastructure are crucial for developing the energy system. This study aims to examine socio-economic and environmental aspects of energy resource usage in Mozambique and the evaluation of Mozambique's power supply alternatives into the future.

Using energy modelling approaches the study simulates different pathways and projects future trends of the energy system, constructing scenarios from current trends and historical data. The scenarios assist to identify policies and strategies that support Mozambique's development with the least cost and environmental consequence. The demand and supply side models of the country were built using the Long-range Energy Alternative Planning System (LEAP) and the Model for Energy Supply Strategy Alternative and their General Environment Impacts (MESSAGE) respectively.

The demand and supply models outcomes showed that in an attempt to increases energy access from 16% in 2010 to 75% in 2040, electricity demand rises from 10240

Gigawatt-hour in 2010 to 80120 Gigawatt-hour in an optimistic scenario and thus, requiring an increase in power generating capacity from 2251 Megawatt to 11.6 Gigawatt, adding not only fossil fuel technologies, but also renewable technologies.

Since electricity generation costs from thermal power plants are expected to increase considerably, due to the rising of fuel prices, especially for diesel units, addition of renewable technologies contribute significantly to reduction of carbon emission, saving of fuel and energy security.

Keywords: *energy model, energy resources, power generation, sustainable options*

CHAPTER 1- INTRODUCTION

1.1. The scope of the study

Many of today's global problems arise from the availability and use of natural resources. Natural resources provide fundamental life support in the form of both consumptive and public services, where energy is indispensable. Poverty alleviation and development depend on universal access to energy services that are affordable, reliable and of good quality (Reddy, 2000: 40).

The economy of Mozambique has been growing quite rapidly in the last decade and this economic growth has been generating considerable pressure on currently exploited local energy resources, increasing the country dependency on imported energy resources, mainly oil products, essential for the industry and transport sectors.

Even though Mozambique is rich in hydropower, oil for small generators is currently used quite extensively for electricity generation. The recent increases in oil prices is affecting electricity generation, hindering the growth of industrial production and forcing a stepping-up of imports of products which could otherwise have been locally manufactured. In fact, the country can no longer afford the use of oil as a fuel for generation of electricity.

As Goldemberg (1988: 202) states, in developing countries, the electricity crisis is primarily associated with the growth of the industrial sector and its rising demand for electricity. Even in hydropower rich countries, the rapid influx of power intensive industries, particularly electrometallurgical industries, such as aluminium, can throw the electricity supply demand situation out of balance. In the case of Mozambique that phenomena occurred with the commissioning of the Mozambique Aluminium Smelter (MOZAL).

Mozambique has a vast potential of energy resources which are not fully exploited, particularly in the power sector. Apart from hydropower, natural gas and mineral coal, Mozambique's diverse energy resources include biomass, solar and wind. However, despite the existence of these resources the energy needs of the country have not been adequately satisfied. This situation is mainly characterized by:

i) Mozambique's poor power sector in terms of technology mix;
ii) Mozambique's dependency on imported electricity;
iii) Shortage of electricity supply for new industrial sites;
iv) Low access to modern sources of energy by the large majority of the Mozambican population.

In an attempt to overcome these concerns a question may be raised:

- Which options should be adopted in Mozambique regarding energy resources usage in the power sector?

For Mozambique, the finding the optimal power generation mix for sustainable development remains a challenge and for that reason, studies on the energy resources area would be helpful. Almost all the electricity of Mozambique is produced by the "*Hidroeléctrica de Cahora Bassa"* (HCB) which has an installed capacity of 2075 Megawatts (MW) but due to the existence of large reserves of coal and gas, Mozambique is intending to generate electricity from coal and increase the generation from hydro and gas.

In that context the Government of Mozambique approved the construction of Benga and Moatize coal power stations, which initially will produce 500 and 600 MW of electricity respectively. Gas power stations, with total installed capacity of 252 MW are already operating in Maputo and Inhambane provinces. Nevertheless, power projects have long gestation times compared to the gestation times of other industries and, at low levels of industrialization and total electricity consumption, a few power-intensive projects can drastically outstrip supply (Goldemberg 1988: 202).

Therefore, this new strategy for the power sector of Mozambique not only will diversify the sources of energy and balance the usage of energy resources but also will bring new technologies to the country and help to expand the areas of knowledge. However, before choosing energy options regarding energy resources exploitation and usage it is important to assess the sustainability of these options from both economic and environmental perspectives.

Considering the case of Mozambique this study looks to answer the following questions:

- Will the usage of coal and gas in electricity generation contribute to develop the power sector and the economy of the country?
- To what extent does the usage of these resources meet all dimensions of sustainability for the country?
- How can Mozambique deal with the issues related to the use of carbon fuels in the power sector?

Mozambique is intending to join to the Extractive Industry's Transparency Initiative (EITI) that meets transparence in usage of exhaustible energy resources such as oil, gas and mineral coal. The EITI is a global initiative supported by the World Bank and the International Monetary fund (IMF), focused on developing countries rich in minerals and hydrocarbons.

The EITI's first principle defends that the prudent use of natural resource wealth should be an important engine for economic growth, contributing to sustainable development and poverty alleviation (EITI, 2011: 10). Since 2009 Mozambique has been working on the EITI member application process and significant progress has been made for full admission to the EITI. In that context, the country achieved EITI candidate status 2012 (EITI, 2013: 10).

As a member of EITI, Mozambique is committed to publish annually, a detailed report on the payments made by mining companies. In that context, the auditing firm Ernst & Young and the EITI Mozambique developed and published in 2012, the report of accounts reconciliation referent to the year 2010 (EITI, 2013).

1.2. Research objectives

This study aims to assess the economic and sustainable use of Mozambique's resources in electricity generation using energy modelling approaches in order to make an integrated social cost-benefit analysis for the power sector and the economy of Mozambique. Energy modelling has multiple purposes such as better understanding of current and future energy markets – supply, demand, prices; facilitating a better design of energy supply systems in short, medium and long term; ensuring sustainable exploitation of scarce energy resources; understanding the interactions between the energy system and the rest of the economy and understanding the potential implications to environmental quality.

Considering that all available fossil fuel energy resources are valuable and its use generates different social, economic and environmental impacts there is a need to define a strategy that ensures a sustainable and rational use of these resources. The need for this research is reinforced by the fact that Mozambique is a developing country with limited financial and skilled labour resources to support its economic growth and thus the economic future of Mozambique is critically dependent on an efficient usage of energy resources in the power sector.

This efficient usage of energy resources will reduce production costs, the waste of natural resources and the pollution of the environment and at the same time will monetize investments in both resource extraction and power generation processes.

1.2.1. Specific objectives

In order to fulfil the overall objective, the following were the specific objectives of the study:

- ✓ To collect data about electricity production, supply, demand and costs in Mozambique, from 2005 to 2010;
- ✓ To analyse the data collected and then develop energy model building scenarios and making projections for 30 years using the energy modelling tool LEAP (Long range Energy Alternatives Planning System);
- ✓ To analyse the projections and assess the socio-economic contribution of all the diverse energy resources in the power sector of Mozambique;

- ✓ To assess the optimal technology mix in electricity generation using the energy optimizing model tool MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environment Impacts);
- ✓ To suggest strategies and policies from the results.

1.3. Methodological approach

The multidisciplinary nature of this research required the application of qualitative and quantitative methodologies. The qualitative methodology focused on observation generating the point of view of the researcher and the quantitative methodology on collecting data and verifying existing theories. According to Wisker (2001: 178) observation can be a rich source of information enabling the researcher to capture with appropriate instruments what people do rather than what they say they do.

An agreement for data collection was established with the Mozambique Power Company (EDM), the Ministry of Energy "*Ministério da Energia*" (ME) and the National Energy Fund "*Fundo Nacional de Energia"* (FUNAE). Alongside, non-participant observation method was used to capture relevant information visiting gas mining (the Sasol Petroleum Temane) and power stations (the Temane gas power plant).

Secondly a literature review focusing on understanding other studies related with power generation, electric utility planning, energy option, development and economy was performed. Emphasis was given to the concepts of generation planning and operation costs of power plants, in order to compare the unit costs of different technologies over their economic life, enabling to perceive the optimal load dispatch problem of electricity.

Finally the LEAP (Long range Energy Alternatives Planning System) and the MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environment Impacts) were used to build the energy model for socio - economic and environmental aspects assessment and optimizing analysis respectively.

1.4. Thesis outline

The rest of the thesis is structured as follows: Chapter 2 describes Mozambique, its features, history, economy and social patterns alongside with the main energy resources currently used in Mozambique.

The third chapter addresses the power sector of Mozambique in terms of power plants (hydropower, thermal plants and other small sources) and the new planned power plants, assessing the development and perspectives of the sector alongside with the relevant socio-economic, technologic and environmental aspects of the power sector.

The fourth chapter describes the modelling tool (LEAP) and the optimization model (MESSAGE). The interpretation of the results generated from the modelling tools is made in the fifth chapter and then the contribution of both renewable and non-renewable energy resources in electricity generation is discussed, assessing economic and environmental issues related with the usage of these resources from the results. Finally, the sixth chapter summarizes the study presenting the relevant point of views and conclusions.

The main data collected for the study are organized in the appendices along with the computed results. Appendix A summarizes demographic and development data, appendix B and C contain the data related to existing power plant output, electricity available, electricity demand, number of customers and their consumption. The demand and supply models results are summarized in the appendix D and E respectively.

CHAPTER 2 – MOZAMBIQUE’S PROFILE AND BACKGROUND

2.1. Introduction

Mozambique is a country located on the eastern coast of the southern region of the African continent. It is a member of Southern Africa Development Community (SADC) and in terms of extent is the thirty fifth largest country in the world and the fifteenth in Africa, covering approximately 800 thousand km square (98 % land and 2% inland water). Mozambique shares borders with Tanzania to the north, Malawi and Zambia to the northwest, Zimbabwe to the west, South Africa and Swaziland to the southwest. To the east the country is bordered by the Indian Ocean, specifically by the Mozambique Channel.

Administratively Mozambique is composed of 10 provinces, with Maputo being the capital. The official language is Portuguese as a legacy of colonialism but there are seventeen other indigenous languages spoken in the country. The country is characterized by diverse culture and the most dominant religions are Catholic and Muslim. The currency of the country is *metical*, adopted in 1980, five years after the independence, thereby replacing the *escudo* imposed by Portugal.

According to the National Institute of Statistics “*Instituto Nacional de Estatística”* (INE), Mozambique’s main rivers are the Zambezi (820 km), Rovuma (650 km), Lúrio (605 km), Massalo (530 km), Licungo (336 km), Save (330 km), Pungué (322 km), Búzi (320 km) and Maputo (150 km). The climate varies from tropical to sub-tropical which is moderated by the influence of mountainous topography of the north-west region of the country. The highest point of the country is Monte Binga, which is 2,436 meters above sea level. The temperatures range between 24.1 ºC - 41.5 ºC in summer and 7.4 ºC - 26.5ºC in winter (INE).

2.2. Demography situation

According to INE, for 2012, the projected population was around 23.7 million. Even considering the existence of relevant urban areas, two third of Mozambique’s population lives in rural areas, distant from the main roads, contributing to characterization of Mozambique as predominantly a rural country. Mozambique's population density for 2012 was approximately 29.6 inhabitants per km^2. Figure 2.1 below, illustrates the upward trend of Mozambique's population in the last seven years with an average growth rate of 2.4% per year.

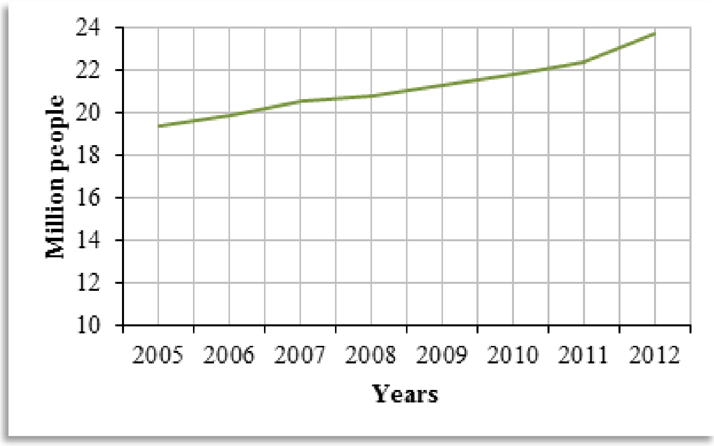

Figure 2.1 – Mozambique's population (data source: INE)

2.3. Political history

In relation to the history of Mozambique it is important to highlight three phases: the colonization of the country by Portugal and the achievement of the independence; the civil war and conclusion of the peace agreement and finally the transition to a democratic system.

The effective colonization of Mozambique by Portugal began around the eighteenth century and went through many phases characterized by multiple resistance movements to colonial occupation. However, the fighting for independence began officially in 1964 and after ten years the country achieved its freedom and proclaimed its independence in 1975 as the Popular Republic of Mozambique. Unfortunately the period of peace and freedom lasted only a few years. In 1976 Mozambique plunged into a deadly civil war which destabilized the country and the economy that was emerging after independence.

The Mozambican people as well as some individuals of the belligerent parties facilitated the initiation of discussions for the peace agreement which was signed in 1992. A new constitution was adopted in 1990 opening the country into a multiparty state as Republic of Mozambique. Since the first democratic election in 1994, the people of Mozambique have enjoyed freedom and peace with a strong government and economy growth.

2.4. Economy and development

Any economy is strongly linked with development which is subsequently associated with the satisfaction of the population's basic needs. Looking at the history of Mozambique, the economy and its development can be analysed in two tranches: before the multiparty system (1975 - 1994) and after the first elections (1994 - 2011).

In the first period, according to Castelo-Branco (1995: 580), after the independence, Mozambique began the difficult and complex task of consolidating the nation. The philosophies, objectives, strategies, policies and development programs were modified in response to structural crises, internal pressure and opposition, changes in the international environment, new models and trends of economic thought and pressures from donors.

In just two decades, the national economy had undergone tremendous shocks: from the structural crisis of colonialism to the "free" market, passing through a phase of centralized orthodox "socialism", Mozambique transitioned between extremes without ever solving the underlying problems (Castelo-Branco, 1995: 580). The government had done everything possible to stimulate, stabilize and make the country's economy more efficient: Centralized the capital and the power in the governmental institutions, monopolized the trade and nationalized the companies in order to run a successful economy.

Nevertheless, because the country was still young, with limited infrastructure, little experience and few experts in the key areas of the economy, Mozambique did not develop as desired. Alongside with these factors, the war that had emerged in the country further complicated the possibilities of Mozambique's development, destroying the little infrastructure that had been inherited from the colonizer.

In less than two decades, distinct economic strategies were designed and adopted by the same government: the perspectival economic plan "*Plano perspectivo Económico*"

(PPI) adopted in 1980, aiming to eliminate the underdevelopment inherited from the Portuguese colonialism and the Economic Rehabilitation Program "*Programa de Reabilitação Económica*" (PRE) initiated in 1987 financed by the World Bank and International Monetary Fund, focused to repair the mistakes of the PPI (Castelo-Branco et al., 1995: 598).

The liberalization and privatization became the focus of the Economic Rehabilitation Program, because they were seen as background solutions to the stabilization of the economy and the attraction of foreign investment. The country was getting into transition stage, shifting from a centralized economy to a decentralized economy. These economic options, associated with the introduction of the multi-party system and the peaceful environment in the country, boosted the economy in a more optimistic direction. As can be observed in the figure 2.2, Mozambique's Gross Domestic Product (GDP) has been showing an upward trend. Mozambique's GDP growth rate was about 7% per year in the last decade.

With public, private and external capital the reconstruction of country and the construction of new infrastructures began. However, with Mozambique's weak financial resources, the country depended heavily on foreign aid and this dependence has been leading to cyclical fluctuations of the economy.

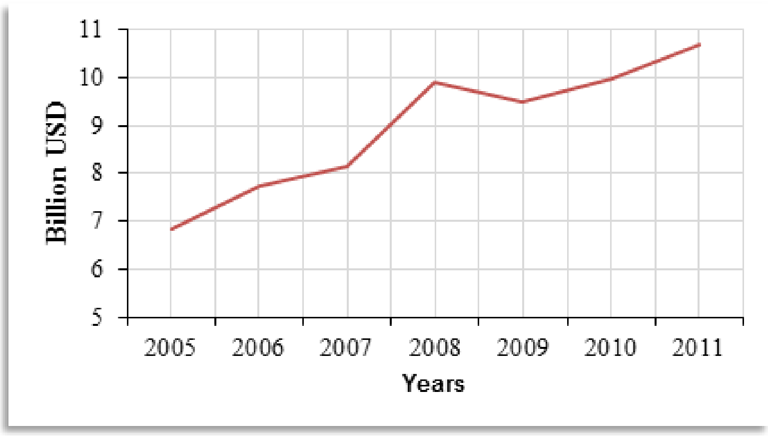

Figure 2.2 – Mozambique's GDP (data source: INE)

Mozambique's government policies for sustainable development and stabilization of economy define priorities areas as: Infrastructures, industry, tourism, health and education. The infrastructure component being transversal to development of other components, the government focused on upgrading roads, bridges, ports and airports in order to improve the linkage between different regions of the country and increase the import and exportation of resources. The main products that the country export are: aluminium, electricity, natural gas, tobacco, wood, minerals and cotton.

One of the great achievements in improving infrastructures is the construction of the bridge over Zambezi River in the Caia district, linking the north and the south of the country. The rehabilitation of the national N1 road, the upgrade of Beira, Maputo and Nacala ports, the construction of new airports of Maputo and Nacala, the expansion of educational and health facilities are other achievements to highlight.

The industrial sector has been growing significantly with the emergence of small and medium industries and mega projects such as MOZAL and Moma heavy sands. However, Castelo-Branco (2010b: 148) states that although the industrial production has been increasing significantly, the composition is concentrated around a small range of primary products and this concentration process was accelerated with the commissioning of the MOZAL. Therefore, the economy is currently boosted by the mining industry.

Regarding the tourism, the Government's program for the period 1995-1999, defined tourism as a sector to boost foreign currency earnings, increase employment and enhance regional development, in order to project a prestigious image of Mozambique abroad, promoting greater participation of national entrepreneurs in tourism enterprises. From 1996 to 1998, the investment in the sector was around 140 million USD, generating revenues of 104.33 million USD. The number of individuals that could be accommodated increased from 7.768 in 1996 to 12.215 in 2002, states de Ministry of Tourism "*Ministério do Turismo*" (MITUR).

Looking to provide suitable health care to the population, the government expanded health facilities to rural areas. According to Ministry of Health's "*Ministério da Saúde*" (MISAU), rural health facilities reached 1.145 units in 2007. Educational infrastructures grew, from 6.495 primary schools in 1998 to 12.604 in 2009, from 87 secondary schools in 1998 to 402 in 2009 and from 33 technical schools in 1998 to 83 in 2009, announced the Ministry of Education "*Ministério da Educação*" (MINED).

Although Mozambique's economy is growing, the country is still in a development stage. Mozambique still lacks infrastructures to enable economic activities and support its fast economy growth. The country is entering in the second stage of its development and needs to move from the very basic infrastructure into a faster mode of growth.

Energy will play a fundamental role in this process. Affordable and reliable energy supply is central to modern economic and social life. Energy strategies have impacts on major issues related to poverty, population, urbanisation and lifestyle. Providing adequate, affordable energy is essential for eradicating poverty, improving human welfare, and raising living standards world-wide, an thus, without economic growth, it will be difficult to address environmental challenges, especially those associated with poverty (Rogner & Popescu, 2000: 31).

2.5. Primary energy resources currently used in Mozambique

Primary energy resource exists in different forms. Some exist as stocks and so are exhaustible; others exist as flows and are inexhaustible. By transformation or conversion processes, primary energy is converted into secondary energy forms at large scale (e.g. electricity from coal), which are then distributed to users as final energy who then use various energy appliances to convert this final energy to useful energy (e.g. cooking, heating, etc.). Mozambique is well endowed in many resources such as coal, natural gas, biomass, water, wind and sun, as sustainable or affordable primary energy resources and the scale of the resource's usage depends on its application, costs and demand.

2.5.1. Coal

Coal is a non-renewable energy resource predominantly used in the industrial sector for heat and power generation. According to Steiner (1946: 79) many fuel technologists have proposed different schemes for classification of coal, using various combinations of chemical and physical proprieties. Using the fuel ratio (percentage of fixed carbon divided by the percentage of volatile matter), coal can be classified as: Anthracite, Semi anthracite, Semi bituminous and Bituminous. Other classifications divide coal into Anthracite, Bituminous, Sub bituminous and Lignite (Steiner, 1946: 82).

In an attempt to systematize the qualities that affect the utility of coal, Steiner (1946: 81) introduced the classification of coal by grade, grading coal on ash content, ash softening temperature and sulphur content. However, what could be done to improve the grade of a coal is washing or cleaning, which reduces both the ash and sulphur content.

Coal occurs almost everywhere in the sediments of lower Karoo in Mozambique. The most important coal-bearing structure is the Zambezi Basin. About 93% of the Mozambican coal reserves are concentrated in this Basin where the reserves are estimated to be round 6 billion tons (Lächelt 2004: 223).

The use of mineral coal in Mozambique began before the independence and in order to run a successful extraction and commercialization of coal, after the independence the government of Mozambique created the company *Empresa Nacional de Carvão de Moçambique* (CARBOMOC E.E) but this company faced difficulties in the performance of its role due to the outbreak of the civil war.

With the end of the civil war, Mozambique being endowed with large reserves of coal has attracted significant investment to the mining sector as a result of great demand for coal worldwide. The availability of coal produced in Mozambique is creating opportunities for its usage in the country in industrial process and generation of heat and electricity. As can be seen in the figure 2.3, the production of coal in Mozambique suffered fluctuation until 2010.

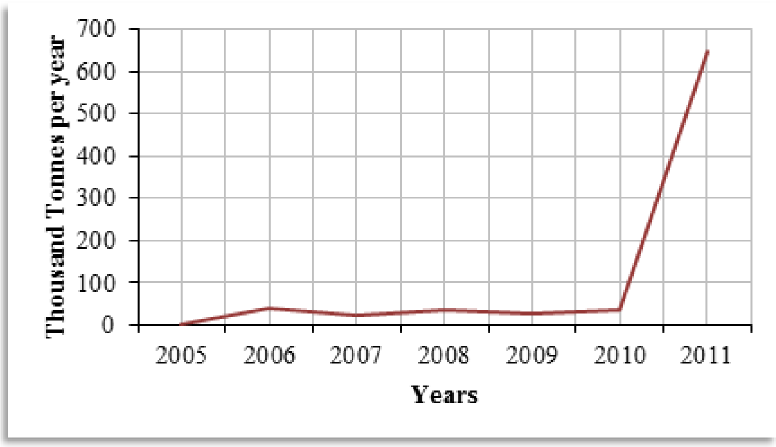

Figure 2.3 – Production of coal in Mozambique (data source: INE)

Since then, Mozambique's Ministry of Mineral Resources "*Ministério dos Recursos Minerais*" (MIREM) awarded several licenses for coal research, many of them in the province of Tete. Multinational groups such as the Brazilian company *Vale do Rio Doce*, the Australian Riversdale Mining, the UK-Australian Rio Tinto and other small mining companies are extracting coal in Mozambique and thus, a rise of coal production is expected. According to (Selemane, 2009: 15), coal production could reach 26 million tonnes per year in the near future.

Works on the infrastructure and utilities required for the project have been extensive, and include development of the 600 kilometer railway line from Sena to the Port of Beira, the construction of a new maritime coal terminal at the port and the construction of a coal-fired power station sited next to the mine. The table 2.1 presents coal quality of Moatize mining.

Table 2.1 – Coal quality of Moatize (Lächelt, 2004: 227)

Physical/Chemical properties	Features
Water	1.1 %
Volatile	17.8 % (dry sample)
Ash	18.1 % (dry sample)
Carbon	70.9 % (dry sample)
Hydrogen	3.8 % (dry sample)
Sulphur	0.7 % (dry sample)
CO_2 (carbonates)	0.7 % (dry sample)
Volatile (corrected)	21.3 % (dry sample without Ash)
Calories (heat power)	6888 kcal/kg

2.5.2. Natural gas

Natural gas is a fossil fuel that contains a mix of hydrocarbons, mainly methane (CH_4), along with varying amount of ethane (C_2H_6), propane (C_3H_6), and butane (C_4H_{10}). Carbon dioxide, oxygen, nitrogen and hydrogen sulphide are also often present (Victor et. al., 2006: 6). Natural gas is dry when it is almost pure methane and wet when it contains other hydrocarbons in abundance. Those longer chain hydrocarbons can condense to form valuable light liquids called natural gas liquids (Victor et. al (2006: 6).

As coal, it is also a non-renewable energy resource with several applications in the industrial and other sectors for heat and power generation. All natural gas is processed to remove unwanted elements that would interfere with pipeline transportation or marketing. Each component has distinct weight, boiling point and other physical characteristics. This makes it possible to separate the components (Chambers, 1999: 25).

According to British Petroleum Company (1972: 248), natural gas, liquefied petroleum gases and manufactured gas can therefore fulfil most industrial-fuels roles more cleanly, more conveniently and in many cases more efficiently than other fuels. These advantages are at their minimum in large scale fuel-intensive industries such as power generation, industrial steam production, iron and steel making and cement manufacture where solid and liquid fuels are used with high efficiency.

In order to manage the exploitation of natural gas in Mozambique the government created in 1981, the national gas company "*Empresa Nacional de Hidrocarbonetos"* (ENH) whose activities focus on research, production and distribution of natural gas. Currently Mozambique's potential in natural gas is approximately 160 Tcf placing Mozambique in the group of countries with the largest reserves of natural gas in Africa.

Multinational companies such as Anadarko Petroleum Corporation, Eni and Sasol are operating in Mozambique in the research and exploitation of natural gas at the Rovuma Basin and Pande –Temane deposits. In October 2010, Sasol Petroleum International (SPI) signed an agreement to explore for oil and gas in onshore concession area covering approximately 8370 km^2 adjacent to the Pande and Temane fields.

From 1988 until 1996, the ENH performed an evaluation of natural gas reserves in the Pande block, discovered in 1960. Since 1992, ENH established a network of natural gas distribution in the districts of Govuro, Inhassoro and Vilankulos, all in Inhambane province which supplies natural gas to 187 consumers, among residences, hospitals and industries.

From the field processing facilities, gas enters the transmission pipeline system for movement to cities where it will be distributed to individual businesses, factories and residences. Gas transmission systems can cover large geographical areas and can be hundreds of miles long. Transmission lines operate at relatively high pressure and compressors provide the energy to move the gas through the pipeline.

From 2000 to 2004, it is important to highlight the construction and operation of the pipeline Temane – Secunda, the construction of the Sasol gas processing station of Temane with a production capacity of 120 million GJ per year and the production and commercialization of natural gas. The figure 2.4 shows that since then, the production of gas increased from 90 million GJ in 2005 to 130 million GJ in 2011 (INE).

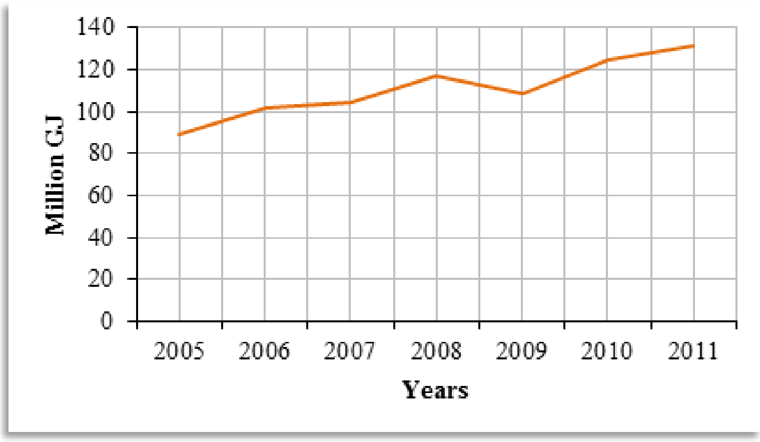

Figure 2.4 – Production of natural gas in Mozambique (data source: INE)

During 2011, Sasol made progress towards completing the expansion capacity of the onshore gas facilities in Pande and Temane from 120 million GJ to 183 million GJ a year. The total gas sales volume from Mozambique increased 17%, from 75.1 million GJ in 2010 to 88 million GJ in 2011, and the gas market of Mozambique is supplied with 27 million GJ of gas per year (SPI). Adding the production of other companies, the total sales volume to South Africa and Mozambique are estimated in 147 and 36 million GJ per year respectively (MIREM).

In Mozambique it is noted that natural gas is used not only in power generation but also in in the transport sector, mainly in the public transport where the government has imported from China buses moved by natural gas. Due to the high price of petrol private vehicles have been modified as well in order to use natural gas.The tables 2.2 and 2.3

present the mix of hydrocarbons of Pande's natural gas and the summary of recent discoveries of natural gas in Mozambique respectively.

Table 2.2 – Natural gas of Pande's mix of hydrocarbons (Lächelt, 2004:222)

Chemistry	Methane	Ethane	Propane	Pentane	Hexane	Octane	Butane	Other
%	*95.5*	*1.6*	*0.58*	*0.09*	*0.07*	*0.04*	*0.75*	*1.37*

Table 2.3 – Recent discoveries of natural gas in Mozambique (ENI, Anadarko, MIREM, 2012)

Basin	Pande - Temane	Rovuma (Golfinho/Atum)	Rovuma (Mamba)
TCF	*3.6*	*100*	*80*

2.5.3. Biomass

Biomass is a renewable energy resource mainly in form of fuel wood, charcoal, crop and wood residues, dung and other solid waste generated from different materials. Biomass is widely used in industry and households for heat and power generation. For example, biomass can be used directly as energy generation in fireplaces for heating. At the present the most advanced technologies are those applicable for electricity generation, those involved in the production of ethanol and substitute natural gas.

According to Karenzi (1994: 10) biomass contributes 35% of the energy used in developing countries but it is almost the only energy resource used by rural people. Biomass, mainly in the form of wood and crops products, constitutes up to 90% of energy resources in some African countries. Developing countries account for 85% of the world's biomass consumptions.

In Mozambique 80% of energy consumption comes from biomass, mainly wood fuel and charcoal, with an annual consumption of approximately 14.8 million tonnes, states the Ministry of Energy. Wood is one of the oldest and most widely used construction materials and today is just as valuable an engineering material. Probably the oldest use of wood has been as a fuel. Several conversion technologies for wood biomass are in varying stage of development.

The Ministry of Energy, states that Mozambique possesses 65.3 million hectares of forest and other vegetation formation with a potential of fuel wood and charcoal production of approximately 22 million tonnes per year. The Ministry of Energy's new strategy for modern and renewable energy sources focuses on promoting the shifting from the traditional biomass system to the modern system such as modern stove and oven, co-generation and gasification of biomass for electricity and heat generation and production of biodiesel, ethanol and gel fuel.

It is important to highlight that the country has experimented recently with the production of biodiesel, ethanol and gel fuel and the Ministry of Energy's biofuel strategy approved in 2009 plans an addition production of 3.75 GW by 2013 for its usage in industrial sector and transport.

2.5.4. Water

Water is a renewable energy source in the form of flow. A great attraction of water is that it is free and does not cause pollution. In the power sector water is not only used in form of flow generating hydropower from its potential and kinetic energy but also as a source for cooling water and generating steam. The potential and kinetic energy of water flowing in rivers or other streams constitutes an important energy source.

Mozambique has 104 main river basins and the basins of major rivers, from south to north, are: Maputo, Umbeluzi, Incomati, Limpopo, Save, Buzi, Pungue, Zambezi, Licungo, Lurio, Messalo and Rovuma. With the exception of Licungo, Lurio and Messalo, all other basins are shared with at least one other country. The Zambezi River Basin is shared by a total of eight countries.

The rivers involving hydropower generation are the Zambezi, where the Hidroeléctrica de Cahora Bassa is located, the Revué, where the Hidroeléctrica de Chicamba and Hidroeléctrica de Mavuzi are located, and the Sabie river, where the Hidroeléctrica de Corumana is located. The figure 2.5 illustrates the typical year water inflow of the Cahora Bassa dam in 2010. As can be observed, the availability of water has seasonal variation. The average availability of water is greater from January to March and the typical dry season occurs from August to November.

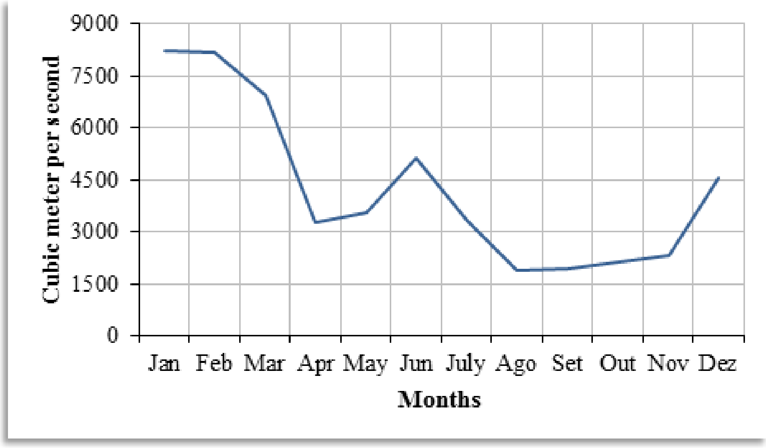

Figure 2.5 –The Cahara Bassa dam's 2010 water inflow shape (data source: HCB)

Similarly, the figure 2.6 shows the typical water inflow of the Chicamba, the Mavuzi and the Corumana dams in 2010. The average availability of water is also significant from January to March and then falls. Consequently, during the dry season, electricity production from hydropower can be affected. Therefore, the capacity factor (CF) during dry season is lower than the capacity factor during wet season. For example, regarding the HCB hydropower plant, CF is about 84% in wet season and about 66% in dry year season.

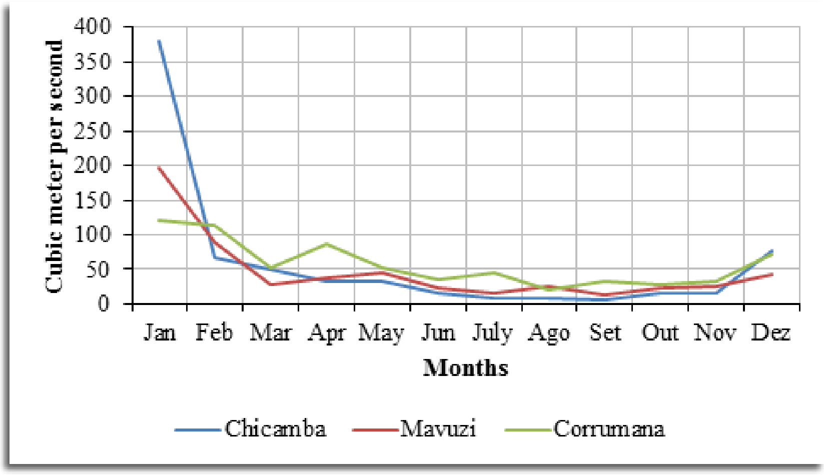

Figure 2.6 – Water inflow shape of the Chicamba, the Mavuzi and the Corumana dams in 2010 (data source: EDM)

2.5.5. Sun

The sun is an inexhaustible renewable energy resource in the form of flow, widely used for heat and power generation. According to the Ministry of Energy, the average of solar energy in Mozambique is approximately 5.7 kWh/m^2, with the minimum of 5.2 kWh/m^2 (Lichinga province) and the maximum of 6.0 kWh/m^2 (Pemba e Chimoio provinces).

With the aim of improving the quality of life of rural population living in areas with no connection to the national grid network, the government of Mozambique created in 1997, the National Energy Fund "*Fundo Nacional de Energia*" (FUNAE), which provides electrification of hospitals, schools, houses and other infra structures using solar system. Recently, the governments of Mozambique and India have signed an agreement aiming to build the first solar panels factory in Beluluane, Maputo province with a capacity of an annual production of solar panels that could generate 5 MW of electricity (FUNAE).

Since its creation in 1997, FUNAE has implemented several projects using solar panels in petrol stations, power generators and water pumps system. Alongside with solar system the fund implemented biomass and smaller-scale hydroelectric power stations projects. From 2001 to 2011, the number of population benefiting from different projects increased from 19 845 to 2 327 197 (FUNAE).

2.6. Socio-economic and environmental aspects of energy resources usage

In its strategy of energy resource usage for sustainable development Mozambique has been confronted with several socio- economic and environmental concerns as a result of social conflicts derived from the exploitation of energy resources, the lack of financial resources for a wide exploitation of energy resources and the safeguard of the environment through the monitoring of the activities of energy resource exploitation.

According to EITI (2011: 10) energy resources exploitation and use when not managed properly, can create negative economic and social impacts. Therefore, any country cannot achieve sustainable development if the exploitation of energy resources generates social conflicts or faces economic and environmental problems.

Because natural resources are such an important source of value for so many people, it is of little surprise that politics and power relations should strike at the heart of natural resource use. Conflicts of various kinds and at multiple levels are the norm rather than the exception. Typically, natural resource management involves changes not just in the physical management of natural resources, but also in the rules and regulations affecting their management. Questions of governance, ownership, use and access rights become critical. (World Bank, 2005: 18).

2.6.1. Socio-economic aspects of energy resources usage

The Government of Mozambique is determined to extract and export its natural resource potential as fast as possible, supposing that this will positively contribute to economic growth and poverty reduction and thus, since 2010, Mozambique's Ministry of Mineral Resources "*Ministério dos Recursos Minerais*" (MIREM) awarded several licenses for coal and gas research in Tete and Cabo Delgado provinces. However, many countries rich in energy resources are among the poorest nations in the world, in spite of decades-long extraction of their natural resources (Bucuane & Mulder, 2008: 137).

Most social-economic conflicts are related with the need of moving population from the area around the mining or the site where the new resource mining project is going to be implemented and the people's anxiety to see a remarkable development of the country reflected in their lives.

According to Selemane (2010), these socio-economic conflicts happened with the Moma Heavy Sands project and the Moatize Coal mining project. In order to build the processing factory the Kenmare Moma Mining needed to move people to another town including the local cemetery. It was a complex process characterized by the absence of dialogue and many people sought to take advantage of the situation to have the best houses in the neighborhood resettlement.

In the case of Moatize coal mining the Vale Mozambique Company moved 1 313 families who lived in the mining area. This process was characterized by many conflicts because it was necessary to consider the different social status of the people to resettle and that procedure was seen as divisive within the community (Selemane, 2010: 21). The Riversdale Mozambique will need also to move people from one town to another in order to run the Benga coal mining project. According to Selemane (2010: 29), this company is expecting to resettle 1 147 families living in five communities in the coal mining area.

People affected by the Riversdale project are eager to have a resettlement process much better than that process passed by those affected by Vale Mozambique. They believe that Riversdale had learnt from the mistakes committed by other mining projects but they are not so certain that the mistakes will not happen again, states Selemane (2010: 30).

These resettlement processes are characterized by high expectations from the people to resettle, not only with regard to new housing but also with regard to infrastructure and facilities. It is known that any new neighborhood needs basic infrastructures such as electricity, water, sanitation system, roads, schools and hospitals and this entails high financial costs.

The expectations also extend to the hope of obtaining employment at the companies extracting that resources and the promotion of sustainable development. Because it is not sustainable to develop a country where some have everything and others have nothing, this is another social concern in the extraction and usage of energy resources. Given this, the extraction and use of energy resources represents a strong challenge for the government of Mozambique and it can also lead to social conflicts and thus, compromise the aspirations of the country to achieve development in the short term.

In that context Mozambique should look at what is happing in other countries in the promotion of sustainable development. For instance, Mozambique, should build small industries and facilities around coal and gas mining that generate jobs and indirectly create benefits for everyone. The involvement of the communities in the resource extraction project is fundamental for constructing a healthy environment in the relationship between the companies and the communities. Stakeholder involvement can be formally or informally.

According to the World Bank (2005: 36), because of the multidimensional significance that energy resources have for their primary users, any operation that does not effectively recognize local populations as stakeholders could be at risk of irrelevance, or worse, as result of adversarial consequences on their part, and there are numerous examples of this kind of “negative” or “perverse” participation in the Bank’s natural resource management portfolio, in both recently completed and on-going projects.

Transparency is probably another important aspect for avoiding social conflicts. It can be done by making public the interaction between the government and the companies extracting energy resources, the contracts signed, the quantity of resources extracted, the revenues received and the way the revenues are spent. Transparency reduces opportunities for corruption through an information effect (Bucuane & Mulder, 2008: 136).

Another economic concern of energy resource use in Mozambique is related to the country’s strong dependence on external investment in order to extract energy resources. According to Castelo-Branco (2010b: 163), external dependence is a key feature of Mozambique’s economy growth pattern and has several inter-related dimensions: scientific, technical and technological, institutional, political and economic.

This is clearly noted in the mining and energy sector where the investments have been made by multinational companies such as Bhp Billiton (Mozambique Aluminum and Smelter), Vale Mozambique (Moatize coal mining), Riversdale Mozambique (Benga coal mining), Sasol (Sasol Petroleum Temane), Anadarko Petroleum Company and ENI (Rovuma gas prospection), Kenmare Moma Mining (Moma heavy sand) and many other companies.

In that context, according to Castelo-Branco (2010b: 141), although the economic experience of Mozambique is often presented as an example of success in promoting rapid growth with stabilization and reduction of poverty, paradoxically, remains dependence on abnormally high rates of external capital flows, both official (foreign aid) and private (foreign direct investment and loans in the international banking system) Therefore, this deep dependence is an indicator of the structural weakness of Mozambique’s economic capacity.

Through public spending, foreign aid funds the trade balance, paying for 60% of national imports (excluding imports of mega projects). The building of foreign reserves is partly financed with resources allocated by international financial institutions. For example, during 2008 and 2009, international reserves of Mozambique were protected by the injection of about 200 million USD by the International Monetary Fund (Castelo-Branco, 2010a: 20).

In order to overcome this concern, Bucuane and Mulder (2008: 137) believe that high extraction rates without appropriate planning with regards to the ways the revenues are spent on productive investments may easily lead to a sub-optimal strategy for increasing prosperity and reducing poverty. They argue that in such cases it is better to postpone the extraction of resources, a strategy which also makes perfectly sense in the actual context of current rising prices of resources in the international market, instead of selling now at a low price. Therefore studies assessing all constraints regarding resource extraction and use are important.

2.6.2. Environmental aspects of energy resources usage

From an environmental perspective, the most important concern related with energy resources use in Mozambique is the challenge of promoting biodiversity conservation and at the same time promoting economic development. Mozambique is experiencing glorious moments of its economy, but still remains a country facing countless difficulties, with its population and institutions struggling to find solutions to the its daily lives problems.

Due to the weak capacity for enforcement of laws in order to protect the environment and monitor activities by the government, the extraction, harvesting, processing and use of energy resources have major environmental implications. Goldemberg (1988: 221) states that developing countries do not have a significant role to play in the global climate change. Poverty alleviation, and an environment for achieving sustainable development are priority goals, but this will require them to make commitment to genuine development, oriented to self-reliant, environmentally sound and peaceful socio-economic progress.

In Mozambique, the major environmental concerns are those linked with the use of energy resources in the households. According to the Ministry of Energy, in

Mozambique 80% of energy consumption comes from biomass. The oldest human energy technology, the home cooking fire, persists as the most prevalent fuel-using technology in Mozambique. Consequently, even though most biomass fuels contain few noxious contaminants, they are usually burned incompletely in household stoves and so produce a wide range of health-damaging pollutants (Holdren & Smith, 2000: 65).

Although the link between fuel wood harvesting and deforestation is far from universal, there are localised cases in which fuel wood demand seems to contribute significantly to forest depletion. Most prominent among these are places, mainly in Sub-Saharan Africa, where commercial charcoal production is practised. In these areas temporary kilns (legal or illegal) in forested areas are used until local wood resources are depleted, then moved or rebuilt elsewhere (Holdren & Smith, 2000: 66).

However, it is important to highlight that the industrial use of energy resources has also environmental implication of great scale. The low efficiency and incomplete combustion process in the burning of carbon fuels release pollutants particularly suspended particulates and carbon monoxide. Fortunately, in the context of multinational companies, the environmental aspects seem to be controlled because most of those companies have a specific department which deals with environmental, health and safety aspects.

For instance, visiting Sasol processing plant in Temane, it was noted that this site has a department with a function of controlling not only the environmental aspects but also the management of waste. In that context all reusable materials are recycled and other waste materials are incinerated and deposited in a sanitary landfill site or collected by specialized companies with contractual agreements with Sasol and sent to appropriate place or given appropriated treatment.

2.7. The horizon of other primary energy resources

In Mozambique the technology of using renewable energy resources is still poorly known, from both technical and consumers perspectives. Currently, the infrastructure for renewable sources capture is scarce. The provision, design, installation and maintenance of renewable energy systems remain a challenge for the country and the mechanisms and policies for promoting and regulating renewable technologies are almost nonexistent.

In this context, the government's strategy for the development of new and renewable energy, aims to develop and promote the implementation of projects in renewable energy sources usage and conversion, in order to meet the national energy needs, sustain economic development and social support programs for poverty alleviation. The strategy covers the systems of direct use of renewable energy sources in domestic, agriculture, commerce, industry or public installation and the conversion of renewable electricity for consumption purposes. In order to evaluate the potential sites of wind energy in Mozambique, FUNAE has installed in the south of the country four towers and a set of sensors for wind and solar radiation speed and direction measurement as a part of the renewable energy project (FUNAE).

With a coastline of about 2,800 km^2 and seas ranging from 3 to 7 meters in height, it is believed that Mozambique has a great potential for the exploitation of tidal and wave energy sources (ME). However this form of energy has not yet been explored in Mozambique and the government's new strategy for renewable energy will focus in researching and development of such energy sources. Regarding the geothermal energy, it must be noted that Mozambique is partially covered by the African Rift Valley, making it likely that there is a large potential of geothermal energy, mainly in central and northern regions of the country (ME).

Oil is another primary energy resource that Mozambique is expecting to be extracted within some years. The Minister of Mineral Resources "*Ministério dos Recursos Minerais*" (MIREN) noticed the discovery of oil in Mozambique but the reserves are not yet known. Oil is a vital energy source for several activities in Mozambique, mainly for the transport sector. Currently the main oil fuel products used in Mozambique are imported. In order to manage the petroleum resources of Mozambique and administer the related operations for the benefit of the society, and in compliance with the existing laws, government policies and contractual commitments, the government of Mozambique created in 2004 the National Petroleum Institute.

CHAPTER 3 – THE POWER SECTOR OF MOZAMBIQUE

3.1. Introduction

When talking about energy, the power sector plays an important role in boosting any economy given the high dependence of industrial processes on electricity. The development of many economies worldwide has demonstrated that the economic growth is directly proportional to the growth of the power sector, not only because of the increase of demand for electricity by the industrial sector but also because of the new modern living of their population.

After independence the government of Mozambique created in 1977, the Mozambique Power Company (EDM) as a state-owned company with the mission to establishes and operates public service in generation, transmission and distribution of electricity. One of its first tasks was to merge all generation centres into one single body in order to fully meet all electricity requirements for the development of agriculture, industry and household consumption in the past. Social, political and economic instability would not allow the implementation of roll out-projects of the national grid (EDM).

Within the economic re-structuring in Mozambique, in 1995, EDM was transformed into a public company by Decree 28/95 of 17 July, inheriting a debt burden associated with hard-return on capital investments carried out and still underway. The "new EDM" (EDM-E.P.), now moved to guiding and conducting its activities with a view to improving the quality of service delivered to the customer with efficient use of electricity, hence promoting its image (EDM).

In the developing world and emerging economies, electricity demand is increasing at significant rates in response to economic and social development. The availability of reliable supplies of electricity has become increasingly essential for daily living for most people in both developed and developing countries. It lights homes and work places, powers computers and enables industrial activity (IEA, 2010b: 142). Mozambique's economy has experienced significant growth in the last decade alongside with the growth of the power sector as result of the growth of population and electricity-consuming devices used in homes and commercial buildings, and by the growth in electrically driven industrial processes.

Due to the dependence of Mozambique's economic development on existing and available electricity, which generation and transmission call for big investments, the government of Mozambique approved the Electricity Act in 1997, aiming to regulate the activities of electricity generation, transmission, distribution and commercialization, including the import and export of electricity by individual or collective persons, of public interest.

3.2. Power generation plants

The potential for generating electricity can exist in a form of mechanical energy, chemical energy or thermal energy. For instance, in thermal power plants chemical energy of fuels is converted to thermal energy which is transformed to mechanical energy in the turbine to useful electrical energy in the power plant generator (Randolph & Masters 2008: 123-131).

Therefore, energy resources provide different forms of energy which by an appropriate conversion process in a specific power station those forms of energy are converted to other, generating electricity. The most common electricity generation power plants worldwide are hydropower plants, fossil-fuel power plants, nuclear power plants, solar power plants and wind power plants.

Fossil-fuel power plants are the most important technology for global electricity production. In 2007 fossil-fuel power plants accounted for 69% of global electricity production share, followed by hydropower with 16% and nuclear power with 14% (IEA, 2010b: 112).

Currently for electricity generation, Mozambique uses hydropower, diesel, gas and solar power plants. Practically all electricity production in Mozambique comes from Hydropower. According to EDM, among the company's power plants, hydropower accounted for 94% of electricity production in 2011.

3.2.1. Hydro power plants

Hydropower is a significant contributor to global electricity production and it is the largest source of renewable electricity today. It has a particular advantage in that it can adjust quickly and flexibly to sudden load changes. Hydropower is divided into large and small systems with the cut-off point between 10 MW and 50 MW, depending on the country. Small systems are usually run-of-river designs. These are normally environmentally benign as they do not alter river flows. They often provide an alternative to diesel generators in rural areas. Hydro is also cheap to operate and maintain and produces no waste or CO_2 emissions (IEA, 2010b: 127).

Determination of the potentials that can be developed economically is very difficult because of hydropower's high dependency on location. Without detailed studies for each individual location, it is practically impossible to specify the cost of hydropower plant. Detailed studies are necessary to determine the potentials with really meaningful accuracy (Czisch, 2005: 110).

The main hydropower plants of Mozambique are the Cahora Bassa hydropower plant (HCB) with an installed capacity of 2075 MW, the Mavuzi hydropower plant with an installed capacity of 52 MW, the Chicamba hydropower plant with an installed capacity of 36 MW and the Corumana hydropower plant with an installed capacity of 16 MW. Regarding small hydropower, EDM owns the Cuamba and Lichinga mini-hydropower plants with an installed capacity of 1.1 MW and 0.75 MW for emergency purposes.

3.2.2. Thermal power plants

In thermal power plants, fuel is converted into thermal energy, then into mechanical energy, and finally into electrical energy. Fossil fuel, in solid, liquid and gaseous form, represents by far the largest source of energy used to generate electricity. The three general classes of thermal power plants are coal, gas and oil power plants. The maximum possible efficiency of a thermal power plant can be obtained from the laws of thermodynamics, without needing to consider details of the fluid flow and heat transfer process involved in the various stages of the plant.

3.2.2.1. Gas power plants

Gas power plant is a type of power station that burns gas to produce electricity by converting the chemical energy of the fuel in thermal energy by combustion process. Gaseous fuels, including natural gas, are the easiest fuels to burn. Gas needs little or no preparation before the combustion. It must be simply proportioned, mixed with air and ignited (Culp Jr., 1979: 171). Natural gas is a clean, economical and second widely available fossil fuel. Because of the methane's chemical structure, the burning of natural gas creates fewer carbon emissions than the other fossil fuels (Chambers, 1999: 54).

Many gas power systems operate in an open loop flow system. In the open cycle, the compressed air is burned with the fuel at high pressure. An open cycle gas turbine (OCGT) goes through the same process as any internal combustion engine and follows the Brayton cycle but is equivalent to closed cycle in the sense that the atmosphere acts as a heat exchange that cools the air entering the combustion chambers (Andrew & Jelley, 2007: 36). Gas turbines are relatively low capital cost devices that can be started up quickly and are employed for satisfying sudden surges in electricity demand. Efficiency of gas turbines is around 40%.

Mozambique possesses vast reserves of natural gas and this energy resource is used to generate electricity in the southern region of the country. The main gas power plant with an installed capacity of 107.5 MW began to operate in July 2012. This power station operates in Brayton cycle (OCGT) and is situated in Ressano Garcia, Maputo Province, at Gigawatt Park. It is powered by natural gas from the Temane gas fields and its output is being injected directly into the national grid of Mozambique on site via a purpose built substation.

The project is the result of a power purchase agreement that Aggreko have signed with EDM, the Mozambique power utility and with Eskom, the South African power utility. This is the first project by a private company to supply power cross-border to two utilities in Southern Africa.

The Temane and Nova Mambone gas power stations with an installed capacity of 6.6 MW and 0.5 MW are owned by the EDM and used to to supply electricity to the southern province of Inhambane. Those natural gas plants operate in Brayton cycle (OCGT) and are powered by natural gas from the Temane gas fields as well. At Temane gas power plant the annual consumption of gas is about 17 million Standard m^3. A Rankine cycle (CCGT) gas power plant with an installed capacity of 15 MW, consuming approximately 1800 kg/h of gas, is owned by the Sasol Petroleum Temane and generates power for the gas processing plant of Temane.

3.2.2.2. Coal power plants

Coal power plant is a type of power station that burns coal to produce electricity by converting the chemical energy of the fuel in thermal energy by combustion process. Then the thermal energy is converted to mechanical energy in a steam turbine to drive an electrical generator.

A number of advanced coal-fired power generation technologies known as cleaner coal technologies, have been developed to improve the efficiency, to reduce and capture CO_2 emissions and reduce other emissions, such as NO_x and SO_x particulates in power generation from coal (IEA, 2011a: 11). According to IEA, innovative designs of advanced commercial plants equipped with carbon capture technology might reach the level of commercial availability and be commissioned by 2020 and thus, there is no commercial operating experience for this technology, since this technology is yet to be demonstrated at a commercial scale in power plant applications (IEA, 2010c). In Mozambique, coal power technology is not implemented yet, but the government approved the construction of Benga and Moatize coal power stations, which initially will produce 500 and 600 Megawatts of electricity respectively.

3.2.2.3. Oil power plants

Oil power plants have the similar energy conversion process as natural gas. Oil and gas-fired power plants are very similar in design and operation to coal-fired units. Mozambique used diesel power plant widely during the civil war as decentralized system, due to the destruction of the national power grid. With the end of the civil war and the reconstruction of the national power grid, many of oil power plants currently used to supply electricity in those districts are not yet connected to main network or for emergency purposes. EDM owns small oil power plants in all provinces, most of them out of order.

Other small power generation from diesel and petrol are also being used in Mozambique for individual and collective purposes in the case of breakdowns in the national energy system. A study visit to the Sasol gas processing plant of Temane allowed to note that this company owns a diesel power plant with a capacity of 1.3 MW used in the case of fault in gas pumping to the gas power station that supply electricity to the Temane site.

However, due to frequent breakdowns of oil plants and the high cost of diesel and its vital importance for other sector such as transport and industry, EDM is planning to convert some of oil power plants to gas power plants and retire others after the completion of the electrification and the connection of all districts to the national power network. The Maputo power plant with an installed capacity of 78.5 MW and Beira power plants with an installed capacity of 14 MW will be converted to gas power plants. Currently, EDM's operational oil power plants totalize a capacity of approximately 65 MW and are scattered throughout the country.

3.2.2.4. Overview of Solar power plants

Solar photovoltaic (PV) is the most important technology for generating electricity using solar power plant by conversion of solar energy directly into electrical. According to Andrews & Jelley (2007: 134), a more efficient conversion (approximately 15%) of solar energy directly to electrical power is provided by photovoltaic (PV) cells. Photovoltaic (PV) can achieve better efficient conversion than solar thermoelectricity or dye-sensitized solar cell. Solar Thermoelectric cells using a solar dish concentrator receiver can achieve efficiency of 11.4% and overall peak power production efficiency for current dye-sensitized solar cell is about 10.9%.

Although the initial capital cost of PV systems are currently high, their running cost should be very modest in comparison with those of other renewable or no-renewable energy sources, not only because they do not require fuel, but also they do not have moving parts and require much less maintenance (Boyle, 1996: 89). In Mozambique solar power plants have been used as isolated systems for individual purposes and although considering the existence of considerable number of PV solar panels being used, the estimated number of units and the global energy production is not known. However, is important to highlight that the effort being made by FUNAE in the implementation of PV system in rural area is contributing significantly to the share of this technology in the global electricity production in Mozambique.

3.3. New power plants projects development

The electricity consumption in Mozambique and the region of Africa Development Community (SADC) is growing at accelerated rates and above forecasts as a result of economic and social growth. The ability to supply electricity during peak hours is in deficit, in Mozambique and in the countries of the region. This requires the construction of new generating capacity among other initiatives focusing on energy efficiency and demand management.

In that context, in 1995 the Southern African Power Pool Plan (SAPP) was created with the aim of developing an integrated generation and transmission system for the Southern African Development Community to coordinate individual expansion plans and derive the benefits of electricity trade within the region. The objective of the SAPP is to provide reliable and economical electricity supply to the consumers of each of the SAPP Members. The potential benefits of coordinated planning include reductions in required generating capacity, reductions in fuel costs, and improved use of hydroelectric energy.

Mozambique has the advantage of possessing many energy resources, renewable and no-renewable. The expansion plans of electric system identify priorities for investment in large and medium hydropower plants and thermal plants to meet the growing demand. Some of these projects are under negotiation and others still in the feasibility study stages. However, the limited available financial capital in the country and the relatively long construction times of these projects, not always located near the transmission network increases the marginal cost of electricity generation (ME).

3.3.1. Hydro power projects

Some of the hydropower projects that are being considered are integrated in the SAPP initiative and others are internal initiatives. The Cahora Bassa North hydropower project is a new hydroelectric power station on the left bank of the existing Cahora Bassa dam, with a planned capacity of 1250 MW, provided by three generators with a capacity of 415 MW. This project is integrated in the SAPP initiative and will share infrastructures with the existing Cahora Bassa Hydropower South, which is an advantage in terms of hydrographical potential utilization and reduction of costs and is expected to operate in 2017.

Other hydropower plants projected to be constructed in the Zambezi basin, Tete Province, are the Nphanda Nkuwa (Included in the SAPP initiative) with a planned capacity of 1500 MW by 2018. The Lupata project with a planned capacity of 600 MW and the Boroma hydropower with a planned capacity of 200 MW are also considered but are without a specific date of implementation. Finally, three other hydropower projects are planned to be constructed: Lúrio with a capacity of 120 MW at Cabo Delgado Province; Malema with 60 MW at Nampula Province; and Ruo with a 100 MW at Zambézia Province, all without a specific dates of implementation.

Regarding mini-hydropower, the FUNAE is running the construction of the Chiuraírue mini-hydro system located at Mossurize, Manica Province, with installed capacity of 23.1 kW, which will supply power to approximately 60 households and public infra structures such as the local health centre, two primary schools, a church and the priests residence, shops and public illumination. In parallel is planned the consignment of the Majaua micro-hydropower project in the Milange district, Zambézia Province with a capacity of 530 kW of power (FUNAE, 2011).

3.3.2. Coal power projects

Coal plays a major role in supporting the development of base-load electricity where it is most needed. Technically, worldwide, a number of advanced coal-fired power generation technologies known as cleaner coal technologies, have been developed to improve the efficiency, to reduce and capture CO_2 emission and reduce other emissions, such as NO_x and SO_x particulates in power generation from coal (IEA, 2011a: 11).

Thereby, though these processes are beneficial to the environment, power companies need to be required or given incentives to incorporate such measures, since typically they add about 10% or more to overall cost of electricity (Andrew & Jelley, 2007: 40). For instance, the government should reduce or waive customs tax, or if necessary subsidize the purchase of more efficient power plants.

Regarding the projects of power generation based on coal, Mozambique aims to take advantage of the exploitation of coal in the Moatize and Benga mining. The Government approved the construction of the Benga coal power plant, with an installed capacity of 500 MW and Moatize coal power plant, with an installed capacity of 600 MW, in order to generate electricity for the coal mines and other facilities in the central region of the country. The Moatize coal power plant project is included in the SAPP initiative and will be implemented by Vale Mozambique by 2017.

According to Vale Mozambique approximately 3 million tonnes of coal per annum will be required to generate the electricity at the power station, which will be built on an area of 300 hectares. In its 2008 statistical report, the EDM power company states that the initial investment of this project is approximately 1.3 million USD. The Benga power plant will be implemented by the Anglo Australian miner Rio Tinto and the initial investment is approximately 1.25 million USD.

While waiting to exploit natural gas in the Rovuma basin, coal power plant will play a fundamental role in the northern region in balancing electricity demand parallel with hydropower. Therefore, taking into account the massive emergence of large economic projects in the central and northern region is given the option of installing projected coal power plants by 2017.

3.3.3. Gas power projects

Due to the availability of huge reserves of natural gas in Mozambique and the existence of natural gas transportation and distribution infrastructure in the south region of

Mozambique, there are ambitious new gas power plants projects under consideration. The Gigawatt Park Station at Ressano Garcia is one of the main gas power project initiatives. The Project entails the development, design, construction, financing and operation of a 232MW gas fired power station (Aggreko, 2013).

The first phase of the Aggreko power plant began operating in July 2012 representing the first interim cross-border Independent Power Producer (IPP) project. Power generated on site was supplied directly into the Southern African Power Pool (SAPP) with the first off-takers from the project being the Mozambique power utility and Eskom, the South African power utility (Aggreko, 2013).

Following the success of the first stage of Ressano Garcia, Aggreko announced in March 2013 that it had signed agreements with both EDM and NamPower, to supply an additional 122 MW from the project. Following this announcement work began immediately to more than double the generating capacity of the plant. As Aggreko designed and built the plant infrastructure to allow for modular increases in capacity, adding the additional power generation was achieved in just 12 weeks (Aggreko, 2013).

Other gas power projects are the Kuvaninga and the Moamba power stations, planned to have a capacity of 60 MW and 700 MW respectively. Parallel, EDM is planning to upgrade the Temane gas station from 6.6 MW to 750 MW and the conversion of the Maputo diesel power plant (50MW) to natural gas power plant (EDM).

3.3.4. Solar power projects

In recent years, solar technologies have developed rapidly. These technologies are still subject to significant learning which, together with economies of scale, should contribute to further significant cost reductions in the future. Currently, their deployment has been subject to a range of incentive schemes that have helped to speed up learning. Photovoltaic technologies can be applied in a very diverse range of applications, including in residential systems, commercial systems, utility-scale systems and off-grid applications of varying sizes (IEA, 2010b: 128).

So far, Mozambique still does not have a plan for utilization of solar energy in the national energy grid. The integration of solar and wind power in the centralized grid, could contribute to diversify the country's supply mix, improving the reliability and the strength of the system. As part of the expansion of the new and renewable energy use, FUNAE continues to plan the electrification of infrastructures with solar system off-grid. In that context, investment for solar system construction was granted by the Republic of South Korea, which will allow building photovoltaic centres for electricity generation by solar panels in the districts of Muenda, Mecule and Mavago in Niassa province (FUNAE).

Other potential new sites were identified at Sofala Province, mainly health center and schools which will be electrified with the support of the Belga Cooperation. Recently, the governments of Mozambique and India have signed an agreement aiming to build the first solar panels factory in Beluluane, Maputo province with an annual capacity of generating 5 MW of electricity (FUNAE).

Despite its characteristic of no dispatchable technologies, solar energy, contribute significantly to saving of fuel, energy security and the reduction of carbon emission. Many studies states that historically, economic development has been strongly correlated with increasing energy use and growth of greenhouse gas emissions. Therefore, renewable energy can help decouple that correlation, contributing to sustainable development.

3.3.5. Transmission network

Regarding transmission and distribution, Mozambique's power sector has 60 substations and 6163 transformers (delivering points). The main existing transmission and distribution lines are summarized in table 3.1.

Table 3.1 – Existing transmission and distribution lines (Source: EDM)

	High and medium voltage						**Low voltage**
Voltage	*533 kV*	*400 kV*	*275 kV*	*220 kV*	*110 kV*	*66 kV*	-
Length (km)	*1420*	*233*	*117*	*1756*	*2530*	*481*	*12353*

The 533 kV transmission line is operated by HCB and is an important HVDC transmission line that provides power export to the South African grid. It transmits 1920 MW of power from the HCB power station to Apollo converter in Johannesburg. The rest of transmission lines are operated by EDM and MOTRACO to supply electricity within the country and export to neighboring countries.

The 400 kV transmission line connects HCB's substation to ZESA network at the central region and the EDM's network to Eskom network and SEB network at the southern region. The 275 kV transmission line is owned by the MOTRACO and connects the Eskom system to Maputo substation and is operated in conjunction with EDM.

The 220 kV transmission line connects HCB (Matambo substation) to EDM network (Chibata substation) and also transports electricity to the northern region. From Chibata substation the 110kV transmission line transports power from Chicamba and Mavuzi hydro power plants to the central region of the country, namely Beira and Chimoio provinces and there is an interconnection with ZESA system. At the southern region there is another 110 kV transmission line which connects the Eskom system (Komatpoort) to Infulene substation. The 110kV system also feeds the rest of the southern region of Mozambique, namely at Lionde, Xai-Xai and Lindela substations. Finally, the 66 kV transmission line is used to interconnect substations at the southern and central regions (EDM).

In relation to new transmission lines, it is important to highlight the high voltage transmission line CESUL and other small transmission and distribution line related with the expansion of electricity network countrywide. Furthermore, there is an on-going transmission interconnection project aimed at construction of a 220 kV double circuit transmission line from Mozambique (Matambo) to Malawi (Phombeya) in the light of the agreement reached between the governments of Mozambique and Malawi on the construction of a transmission line interconnection of about 200 km.

Investment costs related to these projects are vast. For instance, the CESUL project will require investment costs around 2.35 million USD. The project will be run in two phases. The first phase consists mainly of one 400 kV HVAC circuit from Tete to

Maputo. Together with the 400 kV HVAC, it is proposed to install an 800 kV HVDC scheme with one single pole from Matambo to Maputo. The steady state power transfer will be limited to approximately 3100 MW. The second phase consists of the second 800kV HVDC pole. The steady state power transfer will be approximately 6000 MW (EDM).

3.4. Power generation and socio-economic aspects in Mozambique

When choosing energy fuels and associated technologies for the production, delivery and use of energy services, it is essential to take into account economic, social and environmental consequences. Policymakers not only need methods for measuring and assessing the current and future effects of energy use on human health, human society, air, soil and water but also they need to determine whether current and envisaged energy use is sustainable and, if not, how to change it.

Energy is a commodity that should be accessible for everyone, since it promotes the welfare of the citizens as well boosts not only the economic development as well the intellectual development of the people. The magnitude of energy consumed per capita became an indicator of a country's modernization and progress.

Energy concerns have long been driven by one simple preoccupation: increasing the supply of energy. Over the past few decades, however, serious doubts have arisen about the wisdom of pursuing a supply-obsessed approach. Attention is shifting towards a more balanced view that also looks at the demand side of energy where the large social issues reside (Reddy, 2000: 41).

Therefore, the socio-economic analysis of the aspects that interact with the production of electrical power is not an easy task. It is difficult to fit in a more explicit way this issue since it is not clear whether the production of electricity in Mozambique seeks to promote the welfare of communities or aims to generate profits for the companies that produce electricity.

This statement appears as result of the high cost of electrical power connection in the households which is above the minimum wage and due to the large amount necessary for the execution of a safe electrical installation in a residence. In that context, it is understood that there is a legislative gap not only about the social role of the companies providing this valuable service to the citizen as well the character of the energy supply contracts establishing the compromise between the supplier and the consumers.

3.4.1. Social issues

As in many African countries, the striking feature of the power sector of Mozambique is on the one hand the very low access to electricity of its population and on the other hand the availability of surplus power. Long distances, low load factors and low incomes contribute to this low access to electricity (Ranganathan et al 1998: 6). For instance, the density of persons per square kilometres in some areas of the country should not constitute the reason for not expanding electricity but should be seen as a reason to encourage people to immigrate to those areas and create new communities and facilities which will allow decongest cities. On the other hand it is important to highlight that even small groups of people, have the same rights as the big groups of people.

What happen in developing countries is that poor people tend to rely on a significantly different set of energy carriers than the rich. The poor pay more money, or spend more time for energy services, than those who are better off. If patterns of energy use among the poor depress their nutrition, health, and productivity, the poor are likely to absorb the benefits of economic growth only very slowly (Reddy, 2000: 46).

Within the power sector the other matter which may be included in the analysis of social issues is related to the recognition that in any society where there is an interaction between individuals, social issues are always present. The power sector in Mozambique consists of public and private operators that often in the exercise of their activities interact with other institutions or individuals and there is a possibility of emerging social conflict.

Although the character of social conflicts in the power sector is not known publicly, its existence has been recognized by the government and alongside with the approval of the electricity law the government of Mozambique constituted the National Council of Electricity with legal personality and consulting attribute in the interest of the public.

The National Council of Electricity has a function of conciliation, mediation and arbitration in issues regarding the disagreement among concessionaires or between them and their clients in the following areas:

- ✓ the right to supply electricity including refusal or its interruption;
- ✓ quality and regularity of the power supply;
- ✓ conditions and electricity price and transit duties;
- ✓ installation and functioning of measuring and counting equipment;
- ✓ adequateness of the concessionaire’s equipment;
- ✓ refusal or delay in the supply of power by the concessionaire;
- ✓ any other aspect which the concessionaire or any of their clients shall call for the intervention or mediation of the National Council of Electricity.

The Regulation laying down the rules relating to the national network connection approved in 2005 is another instrument established by the government in order to normalize the relation between the concessionaire of electricity and the consumers. The most prominent points of the regulation in the point view of this study are the re-connection which the regulation recommends that must be done in 48 hours.

In the absence of this regulation the consumer is penalized for not paying the power bill, did not have an instrument to restore in time its right of using electricity after payment. This fact often raised disagreements between the consumer and the power supply company. Therefore with all these laws and regulation the government has established principles that make the relationship between the consumer and the electricity supplier friendlier, where the electricity is seen as a public good accessible to all without distinction of social status.

At the internal level, EDM introduced in 2012 the Ombudsman of the company, which among other things shall defend and promote the rights and interests of customers. The introduction of this agent occurs as a result of the lack of timely fulfillment of the customer’s complaint by the institution. The role of this agent is to arbitrate on matters relating to the provision of electricity supply or any other event that results in the provision of this public good. Its purpose is to analyze complaints and give advice or opinions in an impartial way.

3.4.2. Economic issues

Capital investment is crucial for energy development, including investment in plant, equipment, and energy infrastructure. Because adequate and affordable energy supplies are critical for economic growth, any difficulties in attracting capital for energy investment can slow economic development, especially in the least developed countries (UNDP, 2000: 6). In many countries in Africa, one of the key bottlenecks preventing the development of the power sector turns out to be the economy (Ranganathan et al 1998: 5).

In order to meet the demand, the grid must operate 24 hours a day, 365 days a year, meeting and balancing ever-changing levels of demand and supply and it must do so in a cost-effective way, often using an ageing infrastructure. As already old grid infrastructure ages, significant investment is required to update and maintain it in order to ensure reliability.

According to the IEA (2010b: 143), these changes are all challenging weaknesses in the traditional electricity grid. They need to be met by the implementation of new technology and methodologies for the design, maintenance and operation of electricity distribution systems. These need to be better adapted to modern circumstances, such as the emerging growth in consumers wanting to generate their own electricity with the option to sell any excess generation back to the grid.

In the case of Mozambique, the Government through the main power production companies (HCB and EDM) is making efforts to make the power sector more profitable by exporting electricity to other countries. The export of electricity to the countries of the region will monetize the investments made in the electrification of districts they both use the same transmission lines. The alternative is to rely on aid and loans to support the investments of power generation, as was the case for the rehabilitation of the Mavuzi and Chicamba power station, which results from the donation of the Swedish government and commercial credit. The conversion of the Maputo diesel power station in gas power station has secured funding from the company Vale do Rio Doce (EDM).

3.4.3. Environmental issues

The design, location, construction and operation of electrical power generation facilities have been markedly affected by the concern for the environment. The power engineer must have a sincere concern for the environment but he also must be concerned with producing enough power to meet the public demand at the lowest possible cost (Culp Jr., 1979: 275). Therefore the major technological challenge of the power sector is to provide energy meeting ecological sustainability and economy.

The low cost of power generation from fossil fuels has made us increasingly dependent on them, releasing pollutants to the environment such solid particles, fumes, gases and heat which endanger the planet's ecological diversity. The storage of water in hydropower plants leads to an increase evaporation rates and the stream beds of the rivers are flooded and the riparian ecosystems displaced, if not destroyed.

According to the Intergovernmental Panel in Climate Change (IPCC, 2007) total annual emissions of greenhouse gases (GHG) are rising. The main greenhouse gas in the atmosphere are water vapour (and water droplets) and CO_2. These gases absorb infrared radiation and this affects the temperature of the earth. Greenhouse effect is the trapping of infrared radiation and the consequent temperature rise. The table 3.2 presents the amount of CO_2 emission (kg per kilowatt-hour) for different power sources.

Table 3.2 – CO_2 emission (kg per kWh): Source (Andrews & Jelley, 2007: 11)

Source	CO_2 emission (kg per kWh)
Wood (without replanting)	*1.5*
Coal	*0.8 – 1.05*
Natural gas (combined cycle)	*0.43*
Nuclear power	*0.006*
Photovoltaic	*0.06 – 0.15*
Hydroelectric	*0.004*
Wind power	*0.003 – 0.022*

Over the last three decades, GHG emissions have increased by an average of 1.6% per year with carbon dioxide (CO_2) emissions from the use of fossil fuels growing at a rate of 1.9% per year. In the absence of additional policy actions, these emission trends are expected to continue. It is projected that, with current policy settings, global energy demand and associated supply patterns based on fossil fuels will continue to grow.

Considering that the environmental concern of power generation is diverse (Decher, 1994: 627) states that the use of a criterion based on changing or not changing the environment to determine whether a certain energy conversion process should or should not be exercised is a complex task. This complexity is recognised by most studies related to the environmental impacts.

For instance, IPCC (2007) states that the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve the stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system but in the sometime recognize that defining what is dangerous anthropogenic interference with the climate system and, consequently, the limits to be set for policy purposes are complex task that can only be partially based on science, as such definitions inherently involve normative judgements.

On the other hand future GHG emission estimates are highly dependent on the evolution of many variables, such as economic growth, population growth, energy demand, energy resources and the future costs and performance of energy supply and end-use technologies (IPCC, 2011). Achievement of emissions reduction across all energy sectors in an efficient manner will depend on access to the best available technologies (IEA, 2008).

Renewable energy sources can generate electricity with very low net CO_2 emissions over their lifecycle. Therefore, they have the potential to make a significant long-term contribution to decarbonising the power sector. The local availability of many renewable energy sources can also help decrease energy dependence and increase the energy security of countries (IEA, 2010b: 124). An argument in favour of hydropower is that does not produce greenhouse gases or acid rain gases. In the case of Mozambique because the major source of electricity generation is hydropower, can be stated that the power sector contributes with the smallest share in CO_2.

The average CO_2 emission presented by IEA in 2009 places Mozambique in the group of countries with low CO_2 emissions if compared for example with developed countries such as South Africa (table 3.3). However, the growth in electricity generation associated with the implementation of new gas and coal power plant will increase significantly the share of the power sector in CO_2 emission.

Table 3.3 – Million tonnes of CO_2 emission of Mozambique and South Africa (Source: IEA 2009 Edition: II.5)

Year	1990	1995	2000	2004	2005	2006	2007
Mozambique	*1.1*	*1.1*	*1.3*	*1.7*	*1.5*	*1.6*	*2.0*
South Africa	*254.7*	*276.9*	*298.5*	*337.6*	*330.5*	*331.6*	*345.8*

Even though that hydropower is renewable energy source, tends to have large impact on the local population. Over 1.1 million people were to be displaced by the three George dam in China and it has estimated that 30-60 million people worldwide have had to be relocated due to hydropower projects. On the other hand, dams sometimes collapse for various reason (over spilling of water, inadequate spillways, foundation defects, settlement, slop instability, cracks, erosion, and freak waves from landslides in steep-sided valley around the reservoir (Andrews & Jelley, 2007: 79).

Water quality may be affected both upstream and downstream of a dam due to increase in the concentration of dissolved gases and heavy metals. The installation of hydropower can also have a major impact on fish due to changes in the habitat, water temperature, flow regime, and the loss of marine life around the turbine.

In order to reduce the environmental impact and the consequences of dam failure, the question arises as to whether it is better to build a small number of large reservoirs or a large number of small ones. Though small reservoirs tend to be more acceptable to the public than the large ones, they need a much larger total reservoir area than a single large reservoir providing the same volume of stored water.

Taking into account the location of the HCB reservoir, downstream from major population and from areas of intensive demographic, agricultural and industrial pressure, environmental monitoring activities have been carried by HCB in defence of the environment, checking the quality of the water which is transferred to the aquatic systems, that is the habitat for the ecosystems (HCB).

The monitoring also concerns the preservation of water retention, the diagnosis of pollutants discharge, the evolution of the sediments at the bottom of the reservoir and electricity generation infrastructures The HCB reservoir monitoring plan is centred on the strategy for assessing the environmental and ecological conditions of the reservoir, and to contribute to its management in such a way as to control environmental problems related to water pollution and to silting along the entire length of the reservoir annually (HCB).

Properly designed climate change policies can be part and parcel of sustainable development, and the two can be mutually reinforcing. Sustainable development paths can reduce GHG emissions and reduce vulnerability to climate change. Projected climate changes can exacerbate poverty and undermine sustainable development, especially in least developed countries such as Mozambique (IPCC, 2007: 97).

3.5. Government policies and strategies for the sector

The Government of Mozambique has been working on the conception of policies and planning of strategies developed in order to boost socio-economic development and support poverty alleviation programs. The government of Mozambique strategy to satisfy the energy needs of Mozambique has been focusing on electrification. In line with this strategy, since the mid-1970s efforts have been made by the government of Mozambique toward universal access to electricity.

According to the Minister of Energy, large amounts were invested in the last two decades to build new electricity generation facilities, increase generation capacity of existing facilities and increase the high voltage network from about 300 km in 1975 to about 6000 km in 2008. The electricity supply increased from 1696 GWh in 2002 to 4024 GWh in 2011 with an annual average growth of 10%. Despite these efforts, access to electricity increased only from 4.5% in 2002 to about 18% in 2011 (EDM).

Recognizing that the economic development of the country is dependent on the existing and available electricity, and where generation and transmission call for big investments, the government conceived and approved in 1997, the Electricity Act as the general policy for organisation of the power sector and management of energy supply, establishing the legal and general regime of power generation, transmission, distribution and commercialization activities in the territory of the Republic of Mozambique. With this act the government looks to:

- ✓ take advantage of the existing potential of energy resources and contribute to the social and economic development of the country;
- ✓ promote the extension of the national electricity network nationwide in order to ensure access to electricity to the people and entities which are not yet connected to the national electricity network;
- ✓ ensure effective supply of quality electricity to the consumers;
- ✓ develop the power sector in order to boost the socio-economic development, securing an ecologic balance, conservation and protection of the environment;
- ✓ seek alternative technologies of power generation.

In 2009 the council of ministers approved the policy for development of new and renewable energy whose principles focus on economic efficiency, equity and sustainability. With this policy, the Ministry of Energy presented the strategy for the development of new and renewable energy for the period 2011-2025 that sets out the actions to be undertaken during this period in the energy sector.

In the economic scope the policy establishes financial and tax incentives that go from credit opportunities, reduction in costs of technology imports and incentives based on prices and tariffs for energy supply. In the aspect of equity, this policy looks to reduce the gap in energy supply between rural and urban areas promoting a standard lifestyle and decent quality of life for all. In the aspect of sustainability the policy advocates good environmental practices in the supply and utilization of energy. The policy encourages the diversification of energy supply systems through the integration of more efficient and sustainable systems in order to satisfy the need of electricity in in both rural and urban areas, including the option of using solar panel to feed the national electricity network.

Mozambican legislation encourages the participation of the private sector in the efforts of development, through private partnerships or public-private partnerships that have some opportunities in the field of energy, because the government recognizes the role of the private sector in the development of the power sector. EDM in its role of power provider and in the view of the strategy and policies of the government of Mozambique agenda on structural reforms aiming at reinforcing the country's growing tendencies will pursue the following steps in order to meet the challenges of the National Strategy 2010 - 2014, namely:

- ✓ reduce the risk of disruption in the sources of energy;
- ✓ reduce environment degradation due to generation and energy consumption;
- ✓ alleviate energy poverty (resulting in lack of access to the energy sources);
- ✓ diversify the energy mix.

3.6. The electricity market of Mozambique

Demand for electricity has been growing in the last decades in Mozambique as result of the growth of the economy, boosted by the emergence of new industrial sites, the expansion and urbanization of the cities and the liberalization of the market of good and services. Currently the electricity market of Mozambique is not only composed of national consumers but also by consumers throughout the SADC region. This has brought new challenges to the market of electricity, in several aspects such as the introduction of new operators, the changes in demand and generation profiles, operation and deployment of electricity networks.

Currently, the major players in the supply of electricity in Mozambique are EDM, HCB and the Mozambique Transmission Company (MOTRACO). EDM is the national power utility owned by the government and takes part in all electricity supply chain (generation, transmission, distribution, consumer connection, supply and billing). HCB manages and operates power plant and their associated transmission networks that supply power to other national electricity companies southern Africa power pool (SAPP).

MOTRACO, a joint venture company formed by the EDM, the South African Electricity Commission (Eskom) and the Swaziland Electricity Company (SEC), is the third major supplier of electricity in Mozambique and was created in 1998 in order to supply electricity to the Maputo-based Mozambique Aluminium Smelter plant.

3.6.1. Electricity supply

Carrying electric power from the power plant to the consumers calls for transmission grids and distribution grids that interconnect the entire system and enable it to work as an integrated whole. EDM is responsible for the national network and, mini grids and independent systems are under supervision of the Ministry of Energy through the provincial directorates. From 2005 to 2011, the total consumption of electricity by the EDM's customers has been increasing with an average growth rate of 11.5%.as shown in figure 3.1.

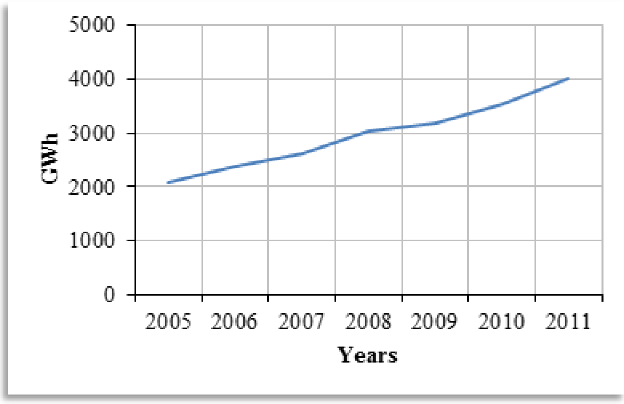

Figure 3.1– EDM's electricity supply from 2005 to 2011 (data source: EDM)

HCB supply electricity from the Songo substation converter which includes all the equipment intended for the conversion of the alternating current from the power station into direct current which is then channelled into the HVDC transmission lines. Mozambique is supplied with approximately 300 MW of the power generated by the HCB, Zimbabwe and South Africa with 400 MW and 1100 MW respectively.

To supply electricity to central and northern Mozambique, two transmission lines were built, linking the Songo substation to the Matambo substation. Among the transmission lines leaving the Matambo substation are a 22 kV line belonging to HCB with a capacity to carry 120 MW, which feeds the Chibata substation. The Songo (in Mozambique) and Apollo (in South Africa) substations are linked by two monopolar overhead transmission lines, covering a distance of 1,400 km, 900 of them in Mozambican territory along the border with Zimbabwe (HCB, 2012).

MOTRACO has a high voltage transmission network that links the Eskom electrical power system in South Africa to the power network of EDM in Mozambique and of SEC in Swaziland. Approximately 12280 GWh of electricity, imported from Eskom transit through this transmission line to the southern region, mostly to MOZAL, which has an annual average consumption of 8440 GWh (MOTRACO).

3.6.2. Electricity demand

According to Stoll (1989: 192), in demand forecasting it is very important to segment the usage of electricity into homogeneous groups with similar consumption patterns. One of the first segment cuts is typically division into three broad classes of customers: Residential, commercial and industrial. However Mozambique's demand side is composed by the residential, the industrial, the agriculture, the commercial, and the special customers.

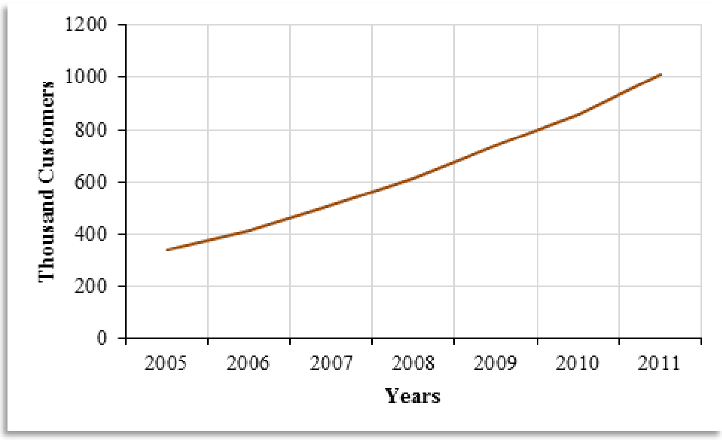

Figure 3.2 – EDM's total customers from 2005 to 2011 (data source: EDM)

Figure 3.2 shows the upward trend of the EDM's customers. The total number of customers registered by 31 December 2011 in Mozambique was approximately one million. The access to electric energy in the country, for a medium sized household of 4 people was 18%. The residential sector accounts for the major number of customers in the electricity market of Mozambique followed by the commercial sector (figure 3.3).

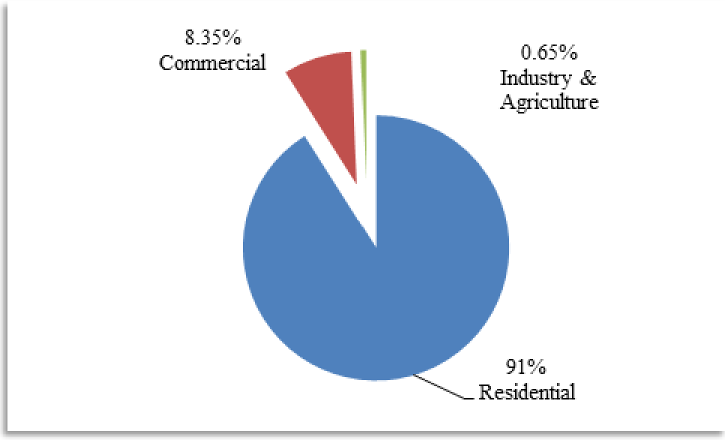

Figure 3.3 – EDM's average share of customers from 2005 to 2010 (data source: EDM)

Peak demand fluctuations may occur on daily, weekly, monthly, seasonal and yearly cycles. As it is shown in figure 3.4, representing the variation of demand from 2007 to 2010, the trend in year peak demand demonstrates a characteristic shape, with lower demand in the winter months and higher demand as summer returns. This trend is probably observed because Mozambique is a tropical country with higher temperatures in summer and the use of air-conditioner equipment occurs practically 24 hours a day. Contrary, in winter, the temperatures are moderated and people can face these temperatures dressing appropriate clotting and thus, there is no need of using heaters.

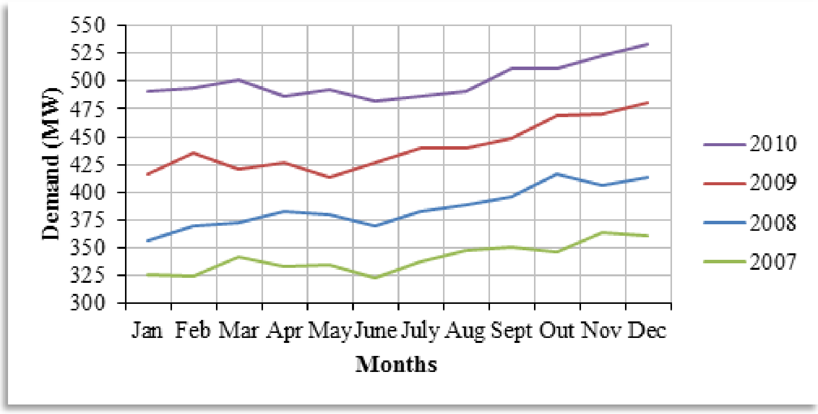

Figure 3.4 – Monthly peak demand in the EDM system (data source: EDM)

For electric sector calculations the year can be split into different user-defined "time slices" to represent seasons, types of days or even representative times of the day. The typical daily demand curves can be draw from existing data dividing the year in season or weekdays and weekends (figure 3.5).

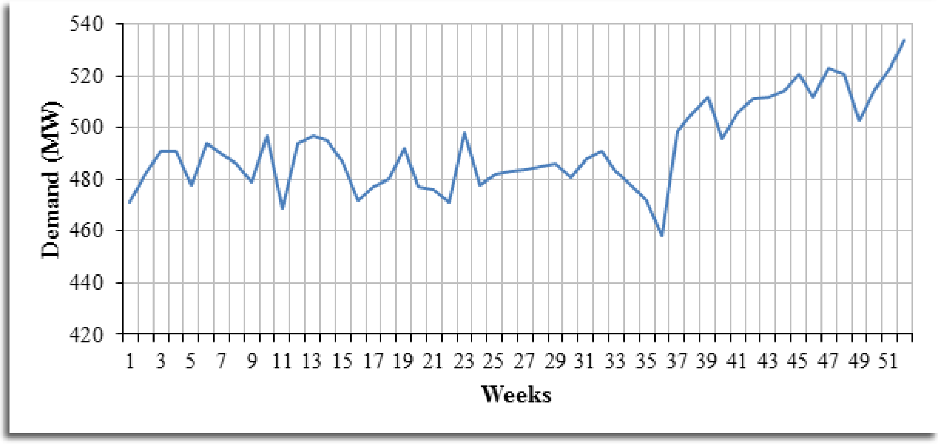

Figure 3.5 – Weekly peak demand in the EDM system (data source: EDM)

These time slices can be used to examine how loads vary within the year and how electric power plants are dispatched in different seasons, enabling one to look in more detail at how energy demand and supply vary. This knowledge will help in deciding what type of plants to develop (base, intermediate or peak-load plants). While all consumers differ in their electrical usage patterns, consumers within a particular class, such as residential, tend to have broadly similar load curve pattern. Therefore, most electric utility distinguish load behaviour on category basin (Willis & Scott 2000: 40). Figure 3.6 represents typical shape of daily demand curve of EDM's residential category.

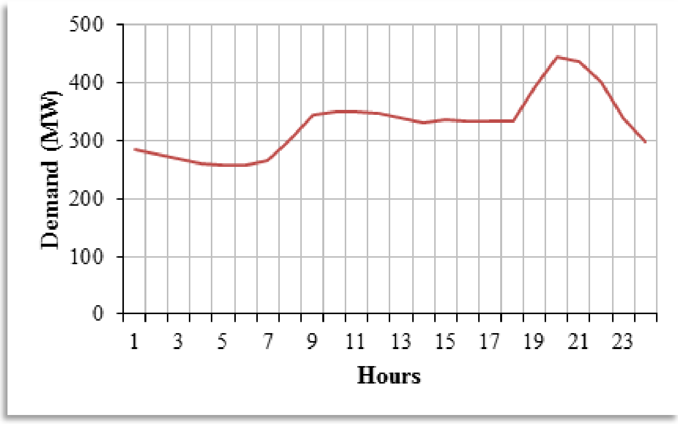

Figure 3.6 – Daily peak demand in the EDM system (data source: EDM)

In order to expand rapidly the access to electricity to the majority of population and face the incoming of new challenges and internal needs, EDM is aware of the need of new investments in the short and medium run in the electric energy new infra-structures in order to meet the demands (EDM). To meet demand, power producers use a base load generation plant (a plant that is kept running to satisfy much of the minimum demand, also called the minimum load). This type of power plants runs at a fairly constant rate. Base load plants are usually the newest and most efficient power plants, therefore the least expensive to operate (Chambers, 1999: 114).

According to Czisch (2005: 109) storage hydropower plants are particularly suitable for load-following operation and peak load coverage. The use of storage hydropower plants opens up interesting opportunities in power plant resource planning for optimising the interaction of all power plants units. They may serve as a supplement to large base load units by being brought in to cover peak load.

For high loads, called peak loads, generators bring the less-efficient power plants online to increase the amount of available electricity. Large system also have plants that are termed intermediate load units, used when the loads exceeds the capacity of the base loads plants, with the peaking load units used only when the demand is at its very highest. During the hottest days of summer, loads will go even higher than that, making use of peaking plants necessary (Chambers, 1999: 144).

According to Stoll (1989: 53), one approximate methods of assessing an optimal generating mix uses an annual load duration curve (LDC) in conjunction with a screening curve. The screening curve is plotted on the top of the graph, which shows the cost of power production per year versus capacity factor. On the bottom half of the graph, a load duration curve plots the megawatt load versus the per cent of the year.

Capacity factor is defined as the total energy produced by a unit within a given time period (MWh) divided by the product of unit capacity (MW) and the number of hours in the time period. For a given period of one year, the capacity factor is expressed as:

$$Capacity\ \ factor\,(\%) = \frac{Year\ electricit\,y\ produced}{(Capacity\ \ of\ \ the\ \ plant)\cdot 8760} \tag{3.1}$$

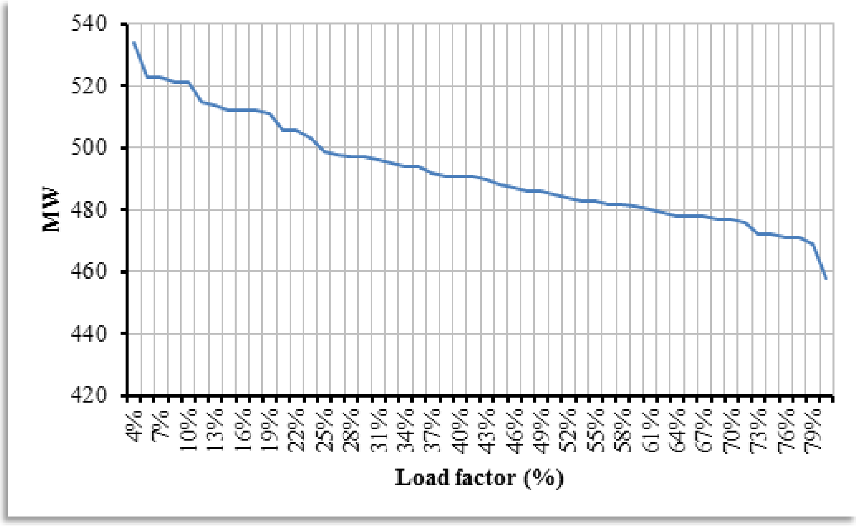

Figure 3.7 – EDM's load duration curve (data source: EDM)

Typical capacity factor for base load range from 50-70%, for intermediate load from 20-40% and for peak load 0-10% (IAEA, 1984: 177). Variations within the ranges depend on unit availability, relative economics and the characteristics of the utility system. The LDC shows the cumulative frequency distribution of system loads. Figure 3.7 shows the load duration curve of the EDM electricity system.

The generation mix of Mozambique is dominated by hydropower, with gas power plants representing only 6% of the EDM's power supply. Therefore, considering that storage hydropower plants are particularly suitable for load-following operation and peak load coverage, both base and peak load coverage are supplemented by hydropower. In order to meet an optimal generation mix in the power sector of Mozambique, in both economic and environmental aspects, it is important to diversify the power sources.

3.6.2.1. Residential

The residential sector accounts for the major number of customers in the electricity market of Mozambique. It is expected that the growth of the residential customers continues due to the emergence of new neighbourhoods and the expansion of the electricity network to the districts. Lighting is the main service needing electricity in the residential sector given that many residential customers do not own many other electric appliances in Mozambique.

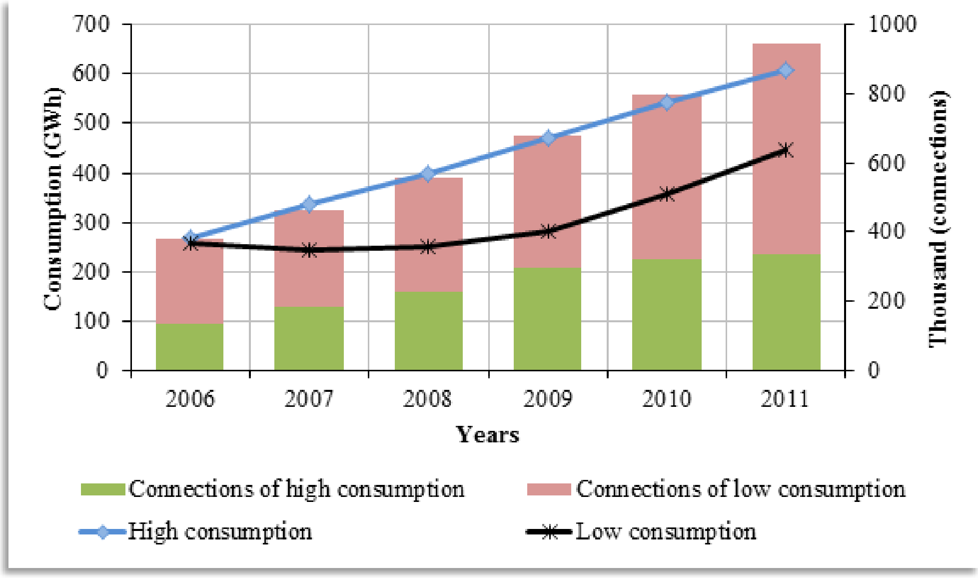

Figure 3.8 – Household connections and consumption in residential sector (data source: EDM)

In that context, the low consumption household accounts for the largest share of the residential sector as illustrated in figure 3.8. In terms of total electricity consumption, it is expected that the upward trend will continue over the next years due to the growth of income in the low consumption households.

3.6.2.2. Industrial

As result of the good business environment in Mozambique, the industrial park has been growing rapidly. This will contribute not only for the growth of the customers in this sector as well for the increased consumption of electricity, requiring more efforts on the part of the EDM in order to satisfy the demand.

The EDM's industrial customers increased from 2920 in 2005 to 4358 in 2010 representing an average growth of 8% per year. In general, the industrial sector can be split into manufacturing, steel and mining industry. Regarding the share on GDP this sector represents approximately 32% of the total income. Figure 3.9 illustrates electricity consumption of Mozambique's industry including the consumption of MOZAL.

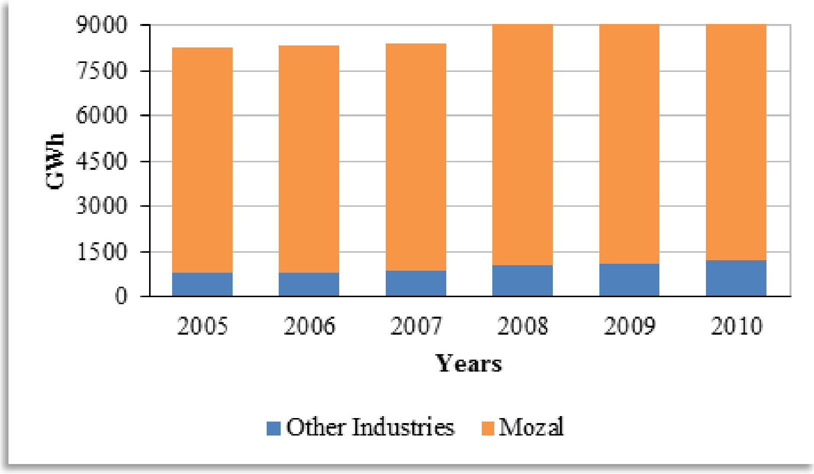

Figure 3.9 – Share of consumption in industrial sector (data source: EDM, MOTRACO)

3.6.2.3. Agriculture

Agriculture accounts for a minor number of customers in the electricity market. From 2005 to 2011, the number of customers increased from 7 to 55 and the consumption of electricity from 0.1 GWh to 0.3 GWh. This probably means that the agriculture sector of Mozambique is dominated by family farms that do not use electricity in their activities.

The growth of the number of customers in this sector has been varied from year to year and thus it is difficult to establish a trend of growth. However, the agriculture sector's contribution on the GDP is about 29% due to the exportation of cotton and wood. On other and, the agricultural activity in Mozambique is dominated by cooperatives who wisely have known to take advantage of the right of association and market liberalization. Therefore, these cooperatives have contributed significantly in the income of the agriculture and commercial sectors.

3.6.2.4. Commercial

The commercial sector represents the second major contributor in the number of customers in the electricity market of Mozambique. This sector alongside with the industrial has been experiencing significant growth. From 2005 to 2011, the number of customers increased from 33809 to 70872 representing an average growth of 13%. In terms of its contribution to GDP this sector represents approximately 36% of the GDP.

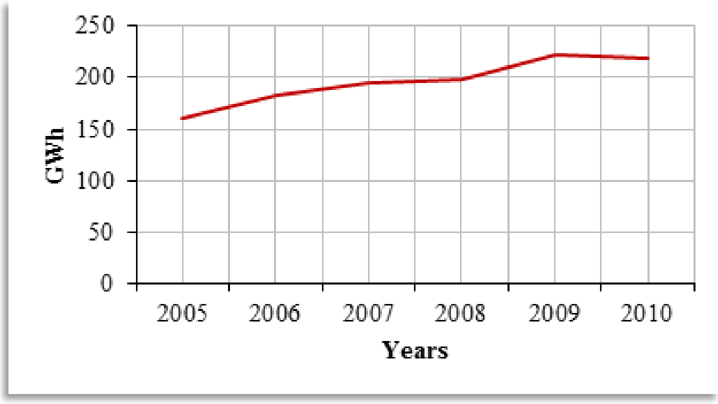

Figure 3.10 – Commercial sector's consumption (data source: EDM)

3.6.2.5. Demand of the SADC region

Through the SADC region EDM has signed a contract with other power companies regarding the supply of electricity and share of electricity infrastructures. Those companies are the NamPower of Namibia, the Botswana Power Corporation (BPC), the Electricity Supply Commission of South Africa (ESKOM), the Zimbabwe Electricity Supply Authority (ZESA), the Swaziland Electricity Board (SEB) and the Lesotho Electricity Company (LEC). Figure 3.11 presents EDM's annual export of electricity to the country of the SADC region.

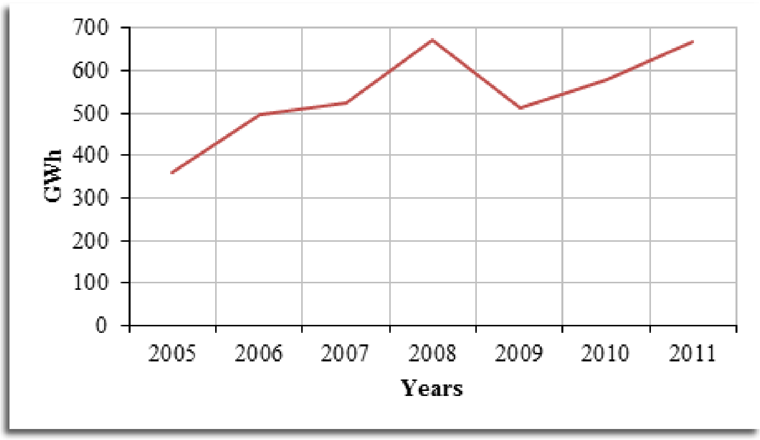

Figure 3.11 – EDM's export of electricity to SADC region (data source: EDM)

3.7. Relevant aspects of the electricity market

Even though Mozambique's electricity market is composed of different players, the market does not give alternatives of choice to majority of its consumers, since is dominated by the state owned company EDM as in many Africa countries. Therefore, currently is a no competitive market. Because electricity is a public service that must be accessible to everyone, the electricity market, before seeking profit, seeks to respond to the challenge of expanding electricity countrywide.

3.7.1. Supply side concerns

The supply of power to a vast country such as Mozambique is complex, since the energy system needs several infrastructures (Power plants, substation, transmission lines and connections). The main concerns that EDM's reports have been presenting are related with:

- ✓ reliable and safe electricity supply;
- ✓ breakdowns, distribution and transmission losses;
- ✓ illegal connections and wasting of electricity.

Since 2005, the total losses of the electricity system, composed by technical losses[1] and non-technical losses are fluctuating between a low of 21% and the peak of 24%. In order to overcome those concerns, many activities were undertaken including:

- ✓ the engagement undertaken to improve and to construct new transmission lines in order to improve the quality and reliability of electricity supply;
- ✓ the improvement of quality and reliability energy supply, through the implementation of redundant systems;
- ✓ the new electrification projects designed in order to eliminate the entrances boxes and thus minimize illegal connections;
- ✓ the installation of automatic metering reading in all substations in order to improve and monitor distribution losses;
- ✓ the consolidation of actions aiming to combat theft and vandalism on energy infra-structures;
- ✓ the rational use of electricity motivated by the introduction of the pre-payment system and the improvement of the commercial services rendered.

[1] Technical losses are related with transmission and distribution losses.

No-technical losses are related with the difference between distributed and invoiced electricity.

As a result, considerable improvement was registered in the performance of the national network. Regarding power generation, EDM has been implementing actions aiming to restore the operationalization of the equipment in the power plants (EDM).

Table 3.3 summarizes the EDM's electricity tariffs in U.S. Dollar per category of customer (currently 1 U.S Dollar ≈ 30, 00 MT). Even though that electricity prices in Mozambique are low in absolute terms compared to many countries, EDM seeks to raise customer awareness regarding the use of energy. In that context EDM is running the project "called more light less energy" which aims to provide low energy bulbs to the customers countrywide. The starting point was the suburban neighborhood in Maputo and 200 thousand lamps were granted by the Portuguese government.

Table 3.4 – EDM's Electricity tariff per category of customers in 2010 (Source: EDM).

Low consumption customers of low voltage (c/kWh)					
Consumption (kWh)	Social	Household	Agriculture	General	Fixed tariff USD per month
0 to 100	*3.57*	-	-	-	
0 to 200	-	*8.33*	*8.93*	*9.90*	*2.85*
201 to 500	-	*11.77*	*12.70*	*14.13*	*2.85*
Above to 500	-	*12.37*	*13.90*	*15.47*	*2.85*
Pre-paid	*3.57*	*10.60*	*12.37*	*14.20*	*2.85*

High consumption customers of low voltage and medium/high voltage			
Category	Consumption c/kWh	Power USD/kW	Fixed tariff USD per month
High consumers of low voltage	*5.53*	*4.26*	*8.33*
Medium voltage – general	*4.57*	*4.77*	*39.10*
Medium voltage-agriculture	*4.13*	*4.77*	*39.10*
High voltage	*4.10*	*4.92*	*39.10*

3.7.2. Demand side concerns

To be dependent on a single energy supplier has also not been easy for the majority electricity consumers in Mozambique and similar to the supply side, the demand side has been facing concerns regarding the right of having reliable electricity day after day, without the fear blackouts.

The main demand side concerns are:

- ✓ the dependence on a single electricity supplier;
- ✓ the constant shutdown of electricity supply;
- ✓ the long waiting time after presenting any failure related to any devise that should be repaired by EDM; and
- ✓ power quality.

Many end users are billed according to the amount of electricity they have used over an extended time period. Therefore, they have no access to detailed information on how or when they are using electricity. So they have no means of readily identifying ways of reducing or shifting their electricity use to minimise their demand and costs.

On the other hand it is noted that the EDM's technical assistance service, due to the high number of complaints and presentation of faults, is not capable to respond swiftly. A project aiming to improve the quality of service rendered to the clients was adjudicated to a consultancy company in order to measure the client's level of satisfaction regarding the service rendered, through public opinion polling.

CHAPTER 4 – MODELLING THE ENERGY SYSTEM OF MOZAMBIQUE

4.1. Introduction

In the real world it is much cheaper for a project team to correct a mistake on a piece of paper than to make changes to an operational system. Computer modelling and simulation is a powerful technique with a broad range of application in all research and analysis activities. A computer simulation model is a logical-mathematical representation of a system, on a computer (Martin, 1968: 3).

In all types of planning, developing scenarios is a practical tool for articulating future possibilities. Scenarios can capture the imagination and thus, can be a tool to generate discussion and creativity about the future. Forecasting is the prediction of future conditions based on projections modified by expected assumptions of driving forces, constraints and opportunities. Forecasts are usually based on models of several factors, such as energy prices, economic growth and population (Randolph & Masters 2008:72).

There are numerous techniques for modelling and forecasting electrical energy and load requirements. In most cases the choice of the method will depend more on the background and time available from the planning staff than on the technical merits of the method. The following scheme of classifying models emphasizes the different ways in which analytical techniques treat customer choice and behaviour. Models are divided into: time series, econometric and end-use methods (IAEA, 1984: 111).

4.2. Modelling framework

According to IAEA (1984: 1), the major objective for an electric power system is to keep a continual balance between the supply and demand for electricity. The government of Mozambique believe that the generation of power from coal and gas will boost the economy of the country, solving the shortage of power for new industry sites and increasing the access of electricity countrywide.

Following conventional economic theory, it is reasonable that total energy use in a country would rise with increases in production and income. For both developed and developing nations there has been an apparently good correlation between energy and gross domestic product (IAEA, 1984: 24). Following that theory, for the demand side modelling, the consumption for the industrial sector, the commercial and the agriculture was linked with the GDP and the consumption of the residential with the GDP per Capita, using the concept of elasticity demand.

Any elasticity is a ratio of two percentages and is expressed as a percentage of change across different commodities. For example, the elasticity of a price can be expressed as a ratio of demand's variation (%) and price's variation (%) (Swisher, Jannuzzi & Redlinger, 1997:28).

$$P_{Elasticity} = \frac{\%\Delta_{demand}}{\%\Delta_{price}} \tag{4.1}$$

Considering that electrical generation system planning cannot be carried out effectively without taking into account the interactions of the energy system with the rest of the economy, the modelling frameworks used are the simulation and optimization applying the top-down approach.

Top-down models are aggregate models based on the historical relationship between energy consumption, prices and income, often macroeconomic that analyse how changes in one sector of the economy affects other sectors and regions. Studies using the top down approach recognize that introduction and accelerated development of advanced energy technologies can have a profound effect on the future rate climate of change. Traditionally, top-down models tend to have little detail on energy consumption and cannot model feedback between economic incentives and technical change very well (Goldemberg, 1996: 119-121).

The methodology used for the model analysis began with the organization and pre-processing of data needed to input into modelling tools, related to:

- ✓ existing generation capacity, new planned capacity and capacity to retire;
- ✓ demand for electricity in all categories of consumers;
- ✓ growth of population and gross domestic product (GDP) and;
- ✓ contribution of the different sectors in GDP.

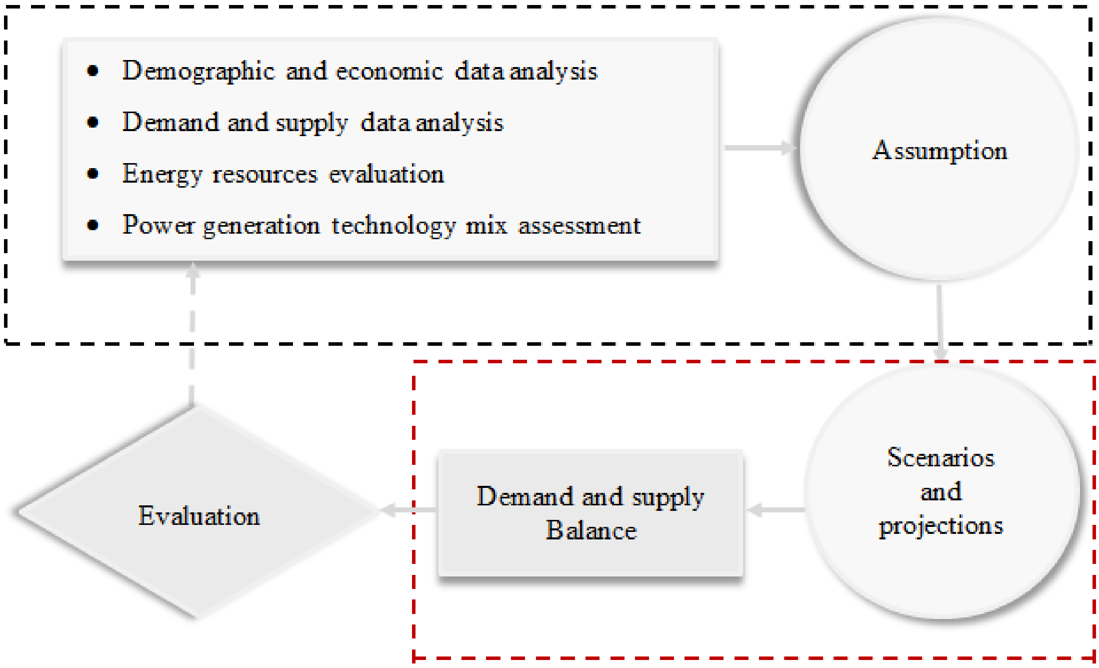

Figure 4.1 – Modelling framework analysis

Since utility decision involves an economic analysis of the operating and investment costs, the utility planning assessment horizon range from 30-40 years into the future. Forecasts with those long lead times are quite a challenge in light of uncertainties in national, regional and local economic growth, coupled with uncertainties in electricity usage patterns and conservation trends.

4.3. Demand forecast

The demand for electricity is dependent on the magnitude and growth of the economy. Robust economic growth creates more jobs, leading to increase population in a service, and thus, consumers who use more electricity. According to Stoll (2004: 168), there are three widely used methods in load energy forecasting:

- ✓ Econometric regression analysis;
- ✓ Appliance saturation methods;
- ✓ End-use energy methods.

The usefulness of each method depends on data availability, customer segmentation, the degree of detail required and the planning horizon. Economic regression analysis uses historical annual energy and economic data to determine customer elasticity.

Econometric forecasting methods are extremely powerful, but the key limitation of those methods is that the future is forecast based on relationships that took place in the past, and so are only useful for short term forecasting. Identification of the driving or explanatory variables is fundamental.

The appliance saturation method is a “bottom-up engineering approach” type methodology. Load research surveys are made to determine the number of customers with a certain appliance (air conditioning, fridges etc.), and the typical annual energy used by the appliance. Then, on the basis of a forecast of number of appliances expected in future, together with a forecast of how the annual energy usage per appliance will change, the energy load is made. This method is commonly used to forecast residential sector energy sales.

The end use energy method is similar to the appliance saturation method, except that instead of using an appliance as the forecast basis, the basis is an end-use process. For example this method can be used to forecast the commercial sector. When 10-15 years of historical data are available, the economic regression methods are applicable. When detailed appliance and end-use data are available, these methods are practical. In some cases, hybrid models are used. Considering the data collected for this study the economic regression method is used to forecast the load demand.

4.3.1. The simulation modelling tool

The energy modelling software tool used is known as Long-range Energy Alternative Planning System (LEAP). This modelling tool developed by the Stockholm Environment Institute, is a widely-used software tool for energy policy analysis and climate change mitigation assessment. It can track energy consumption, production and resource extraction in all sectors of an economy.

LEAP is intended as a medium to long-term simulation modelling tool. Most of its calculations occur on an annual time-step, and the time horizon can extend for an unlimited number of years. LEAP supports a wide range of energy modelling methodologies, including simulation and optimization, and can be used to create models of different energy systems. It also allows data and results from more specialised models to be incorporated.

The modelling tool enables one to examine the contribution of the new planned coal and gas power plants considering the growth in demand. Because some of the generation technologies that are candidates for the future investment do not have significant track records, the supply model was developed taking into account projects with reliable track records and feasible implementation. For example, there is no reliable track records regarding mini-hydro, solar and wind projects that FUNAE intends to implement. In that context, mini-hydro technology is not considered in the study and assumptions had to be made for solar and wind in order to incorporate more renewable technologies in the model and thus, to evaluate their competitiveness with other technologies.

The LEAP modelling tool enabled the examination of the demand side, structured in four categories: Residential, Commercial, Agriculture and Industrial. The electricity consumption in the residential households was divided in low consumption and high consumption households. Regarding the industrial sector, the consumption was separated in manufacturing, steel and mining industries.

4.3.2. Setting the assumptions

Computer modelling and simulation is a quantitative problem and requires information and data for problem solution. When there is a lack of information hypotheses and assumption are adopted to fill gap in the understanding of the problem. Since the key drivers of energy demand are future economic and population growth, projection of these are key assumptions for an energy demand modelling exercise, because according to IEA (2013: 23), demographic factors will continue to drive changes in the energy mix.

Two scenarios were selected for the projections: Borderline and Optimistic. The Borderline scenario can be seen as a worst case scenario, where there is no belief of a strong development of the country. Therefore, the growth rates of energy access, electricity demand and GDP were assumed very low for the demand model. Unlike the

Borderline, the Optimistic scenario is seen as a more ambitious case, with higher growth rates of electricity demand, energy access, GDP and strong development of the country.

Rates of population and GDP growth were assumed looking at the historical data and the analysis and interpretation of the results were assessed by comparing the economic and development characteristics of some SADC countries, mainly South Africa. The comparison with South Africa was chosen because is one of the most developed countries in the SADC region and worldwide in several aspects analyzed in the study.

In the period before 2025, population's growth is assumed to be 2.5% in the Borderline scenario and 3% in the Optimistic. Then, looking at the IEA's projections for Africa, a decrease of population's growth, justified by the fact that, in modern economies, families tend to be small, is expected. Thereby, the country's population (P) in any year (t) can be estimated by the equation:

$$P_t = P_{t_0} \cdot (1+\delta)^{t-t_0} \tag{4.2}$$

Where:

$\delta -$ is the growth rate of population;

t - is the future year and t_0 is the present year.

The global macroeconomic environment has been characterized by instability of the majority economies, reduction of global aggregate demand, rising unemployment levels and reduction of liquidity in the productive sectors. Therefore, a general slowdown is expected in the advanced economies and less rapid growth of emerging economies, particularly in Africa (IMF, 2013: 2-15).

Developing economies have been growing at much faster rates than advanced economies. Nevertheless, the growth of the Mozambican economy has remained stable over recent years, with a real average rate of 7.0% per year. However, assuming the risk of new international conjuncture, expected GDP growth rates will be below 7.0% in the next years (MPD, 2012).

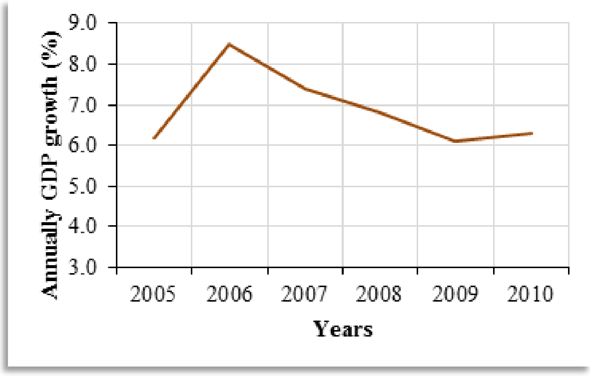

Figure 4.2 – Real GDP growth of Mozambique (Source: MPD/MF/BM)

Projection of GDP growth is considered a hard task, because decisions on growth rates are often dependent on economic and political factors. Examining projected GDP growth rate of different regions in the world presented in figure 4.3, it is noted that GDP growth increases, reaches a peak and then declines.

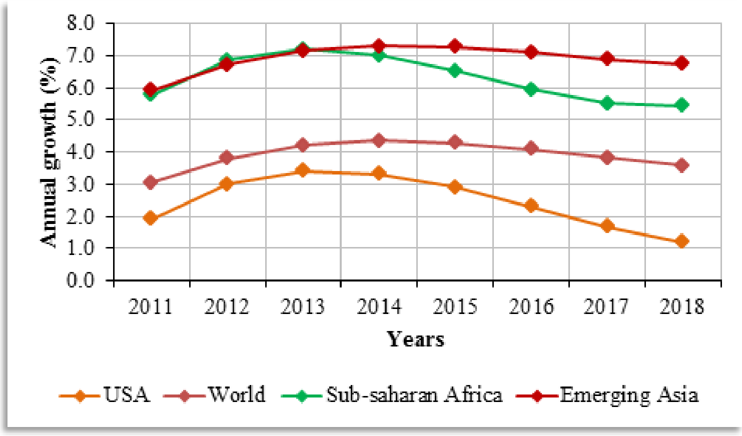

Figure 4.3 – Projected GDP growth rate for different regions (Source: IMF, 2013)

In order to compute the rate of GDP's variation over the period of study, two polynomial functions[2], $y= 0.0002x^3 - 0.01x^2+0.08x+5.7$ for the Optimistic scenario and $y= 0.0002x^3 - 0.01x^2+0.08x+4.7$ for the Borderline scenario , similar to the trend line of Sub-Saharan Africa's GDP growth rate were plotted, taking into account that Mozambique's GDP will continue growing over the next five years near 6% and then will decrease as other GDP growth rate of different region worldwide

[2] In the function, y represents the year growth rate and x varies from year 1 to year 30.

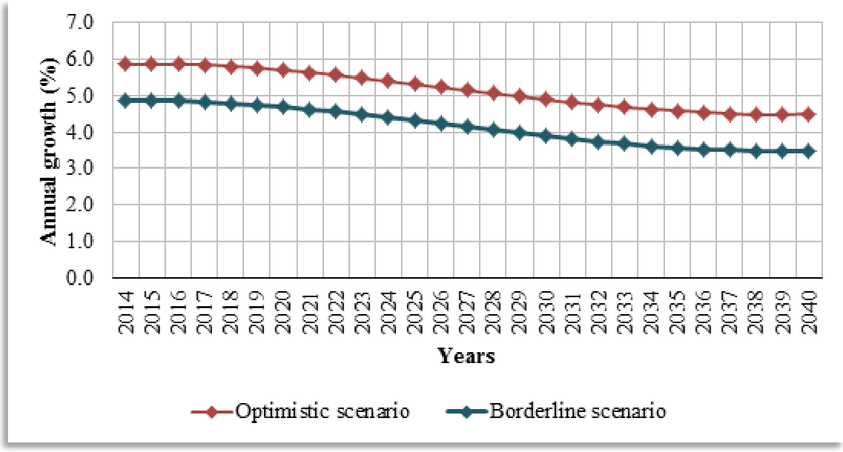

Figure 4.4 – Mozambique's predicted GDP growth rate over 30 years

Therefore, it is assumed that GDP growth rates will be high up until 2020 and then, will slowdown. The country's GDP in any year (t) can be calculated from the equation:

$$GDP_t = GDP_{t_0} \cdot (1+\alpha)^{t-t_0} \tag{4.3}$$

Where, α - is the growth rate of GDP.

Although access to electricity in the country is low, the proposed expansion of the electricity grid to the districts is expected to result in high electrification rates for the country. Therefore, assuming a composition of 4 people per household, for the Borderline scenario, it is expected that access to electricity countrywide will reach 60% by 2025 and 65% by 2040, while for Optimistic scenario, it is expected an access of electricity about 70% by 2025 and 75% by 2040.

These assumptions are set with little optimism in view of, for example, South Africa, the most developed country of the SADC region has not yet reached an access of electricity of 80%. After the 1994 democratic elections, South Africa's government launched the first phase of the National Electrification Program (1994-99), aimed at increasing electrification from 36% to about 66% nationally by 2001 (Davidson & Mwakasonda, 2003). However, since then, South Africa successfully increased the proportion of households that have access to energy to about 75% (DoE, 2012).

The ratio GDP_t/P_t is known as GDP per capita, the ratio population/household size represents the country's household number (*HH*) and the ratio electrified-households/country's household number expresses the portion of access to electricity. When access to electricity's percentage (E_{acc}) is known the electrified households (E_{HH}) are calculated from the expression:

$$E_{HH} = HH \cdot E_{acc} \tag{4.4}$$

A part from the assumptions above, 2010 is used as base year, 2011 as first scenario year and 2040 as end year. Other detailed assumptions of the model in numbers are summarized in tables which form the appendices [3] of this document. Table 4.1 summarizes the main demographic and electrification assumptions of the demand model.

Table 4.1 – Main key assumption of the demand model

Scenario	***Borderline***	***Optimistic***	***Borderline***	***Optimistic***
Period	**2011-2024**		**2025-2040**	
Population growth (%)	*2.5*	*3.0*	*2.0*	*2.5*
Household size (people)	*4*	*4*	*4*	*4*
Access to electricity (%)	*60.0*	*70.0*	*65.0*	*75.0*

4.4. The optimization modelling tool

Many problems in engineering entail the maximization or the minimization of an objective function subject to certain restrictions and trade-offs. The objective function is represented by mathematical function of variables related to each other through restrictions. In order to solve the objective function, different optimization methods can be applied. The most common methods are linear and mixed integer programming, dynamic programming, and decomposition approaches (Burger, Graeber & Schindlmayr, 2007: 155).

[3] See appendix A, and C for data related with the GDP, electricity demand and consumption

The electric power industry has undergone colossal changes in the last decade. Because of such changes, the incorporation of optimization into decision-making has also become inevitable. In electric power engineering, a typical example is that of dispatching generation to minimize the total cost of production, subject to the equality constraint that the sum of generators output is equal to the demand plus losses.

Electric generation capacity expansion optimization programs are designed to evaluate the cost of electricity generation and the installation date of new generating plants for alternative expansion plans over a period of time, such as 15-30 years, and to find the optimum plan. Forecasts with those long lead times are quite a challenge in light of uncertainties in national, regional and local economic growth, coupled with uncertainties in electricity usage patterns and conservation trends. The two major functions are therefore electricity production simulation and capacity expansion optimization.

In this study, the optimization modelling software used is known as the Model for Energy Strategy Supply Alternatives and their General Environmental Impacts (MESSAGE). This software, originally developed at International Institute for Applied Systems Analysis (IIASA) is designed for setting up models of energy systems for optimization. The IAEA acquired the latest version of MESSAGE and several enhancements have been made, most important, the addition of a user-interface to facilitate its application.

The backbone of the MESSAGE is a flexible framework that allows detailed description of the energy system being modelled. This includes the definition of energy forms at each level of energy chains, technologies that are producing or using these energy forms, and the energy resources. The energy forms and technologies can be defined for all steps of energy chains.

The scenarios are developed through minimizing the total system operating costs over a period of time, under the constraints imposed on the energy system. With this information and other scenario features such as the demand for energy services, the model configures the evolution of the energy system from the base year to the end of the time horizon.

4.4.1. Setting the assumptions and constraints

The supply model is designed to formulate and evaluate alternative energy supply strategies. Regarding the optimisation modelling tool MESSAGE, the most powerful features are modelling of relationships between the technologies or between technologies and resources. From historical data regarding electricity demand and consumption, installed capacity, energy resources, and relevant information related with new power generation projects, MESSAGE enables to simulate and optimize an energy supply model in a given period.

4.4.1.1. General assumptions

In this supply model a period of 30 years is defined, as was also defined in the projections of the demand model. Just to highlight, it should be noted that the results of the demand model will be the ones that should be satisfied by the supply model. Excess supply of electricity is exported if economic. 2010 is assumed as a base year and 2011 as a first year of the model.

A real discount rate of 8% was assumed for all investment costs in power generation projects. For an investor, discount rate reflects the return on capital, in the absence of specific market or technology risks. It corresponds to the cost of an investor assuming the certainty of production costs and the stability of electricity prices (IEA, 2010c: 34). Another variable that can have a major impact on investment decision is the exchange rate, since exchange rate volatility can affect the project's investment negatively or positively. Therefore, in order to avoid issue around the exchange rate, the monetary unit used for the modelling is the 2010 US dollar.

The discount rate almost governs the choice of the least-cost solution. A high discount rate will favour low capital cost with high operational cost project alternatives. A low discount rate will tend to weigh the decision in favour of the high capital cost and low operational cost alternatives (Khatib, 1997:50). The objective function of the model is to minimize total discounted costs, including investment costs, fixed O&M costs and variable O&M costs, defined by MESSAGE as:

$$\sum_{t=1}^{t} \beta^t \sum_{i=1}^{n} C_{it} x_{it} \tag{4.5}$$

Where:

$\sum_{i=1}^{n} C_{it} x_{it}$, represents the sum of costs incurred in the period t;

$\beta = \dfrac{1}{1+r}$, represents the discount factor;

r - represents the discount rate;

t - represents the period;

C_{it} - is the costs of the technology in the period t;

i - represents the different costs (investment costs, O&M costs, fuel costs etc.).

MESSAGE computes the objective function, according to the demand, the variables of the technology and the constraints in order to satisfy the equation:

$$\sum Supply \geq Demand \tag{4.6}$$

$$\sum_{i=1}^{i=n} \eta_i x_{it} \geq D_{elec\_t} \tag{4.7}$$

Where:

η_i - is the efficiency of the technology to produce electricity;

x_{it} - is the activity of the technology in the period t;

D_{elec_t} - is the demand for electricity in the period t.

Because money has time value, which is the opportunity cost of capital for the business, the notion of levelized costs of electricity (LCOE) is a handy tool for comparing the unit costs of different technologies over their economic life, and thus, overcoming the uncertainties of the time value of money. In utility terminology, the time value of money is also referred to as the "discount or present worth rate" (Stoll 1989: 38).

For electric utilities, the time value of money can be computed by examining the cost of investment capital or simply the cost of money. The discount rate used in LCOE calculations reflects the return on capital for an investor in the absence of specific market or technology risks. It corresponds to the cost of an investor assuming the certainty of production costs and the stability of electricity prices (IEA, 2010c: 34).

In engineering economic analysis using LCOE, the discount factor (D_F), called present factor value, finds extensive application. For this factor, a future amount in year ***t*** of a value ***F*** is known, and the objective is to find the value of amount at time zero, ***P*** (Stoll, 1989: 41). Discount factor is expressed as:

$$D_F = \frac{1}{(1+r)^t} \tag{4.8}$$

Where, ***t*** is the year (0, 1…n) and ***r*** is the discount rate in percentage. In that context, the value of amount at time zero, $\boldsymbol{P_v}$ also called "the discounted cost or present value" can be expressed as:

$$P_v = D_F * F_v \tag{4.9}$$

Where, $\boldsymbol{F_v}$ is a future amount in year ***t*** and represents the total cost of electricity production is that year, excluding carbon and decommissioning costs. The LCOE expressed in USD/MWh, which represents the amount spent to generate electricity is computed as:

$$LCOE = levelized\ capital + levelized\ O\&M + levelized\ fuel \tag{4.10}$$

In order to calculate the levelized capital, first, a coefficient known as capital recovering factor (CRF) is calculated and then multiplied by the investment cost of the power plant. CRF represents the ratio of a constant annuity to the present value of receiving that annuity for a given length of time. Given the interest rate ***r***, the capital recovery factor is computed as:

$$CRF = \frac{r(1+r)^t}{(1+r)\left[(1+r)^t - 1\right]} \tag{4.11}$$

Assuming that the investment needed for each kW is given the annualized capital is expressed as:

$$Annualized\ \ Capital = CRF \cdot \frac{\$}{kW} \tag{4.12}$$

Where:

$\frac{\$}{kW}$ - is the investment necessary for a 1 kW power plant.

Therefore, the levelized capital in this case is:

$$Levelized\ \ Capital = \frac{Annualized\ \ Capital}{Availability \cdot year\ \ Capacity} \tag{4.13}$$

The levelized cost of power plant operation and maintenance is expressed as:

$$Levelized\ \ O\&M = \frac{Fixed\ O\&M}{Availability \cdot year\ \ Capacity + \text{var}\,iable\ O\&M} \tag{4.14}$$

The levelized fuel is given by the expression:

$$Levelized\ \ fuel = \frac{fuel\ \ Cost \cdot 3.6}{Efficiency} \tag{4.15}$$

The LCOE value enables to compare the costs of different power plants over their economic life. In conjunction with load factor, this cost of generating electricity will determine whether the power plant is suitable for base load, intermediate load or peak load plotting levelized cost curves and annualized cost curves. The levelized cost curves (LLC) and the annualized cost curves (ACC) can be plotted varying the load factor of the power plant. Expressions 4.16 and 4.17 are used to calculate the values related to LLC and ACC.

$$LLC = \left(\frac{annualized\ \ capital + Fixed\ \ O\&M}{Year\ \ capacity \cdot Load\ \ Factor} \right) + Variable\ \ O\&M + Levelized\ \ fuel \tag{4.16}$$

$$ACC = Levelized\ \cos t\ \ curve \cdot 8.76 \cdot load\ \ Factor \tag{4.17}$$

4.4.1.2. Time-slice and load shape assumptions

In order to develop an expansion plan, it is important to have knowledge of how much electricity will be needed and at what times. This is done recording the maximum daily and weekly peak demand in a day at any time or in a week at any day. In Mozambique, daily peak demand is most likely to arise any day at evening (5 pm) and extends up until 9 pm.

Analysing the typical shape of a year demand curve from historical data and noting a seasonal variation of electricity demand, two seasons (summer and winter) were defined. Similarly, analysing the typical shape of daily demand curve of the weeks in summer and winter, the different days of the week were classified in workdays, weekends and holidays according to the similarity in hourly demand.

Even in summer or winter, the weekdays have the same shape of demand curve as it is noted in figures 4.5 and 4.6. However, the shape of demand curve on weekends differs for summer and winter. For example, in summer, Saturdays have a similar shape to Sundays, while in winter the shape of the demand curve is similar of weekdays. Thus, to facilitate the grouping of the weekdays, in both seasons the classifications workdays, Saturday/Sunday/Holidays (SSH) were used.

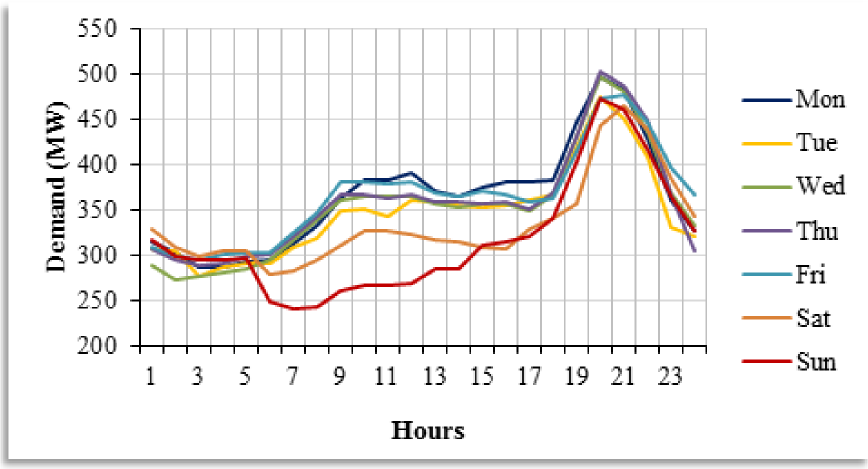

Figure 4.5 – Daily shape of peak demand in the EDM system in summer (data source: EDM)

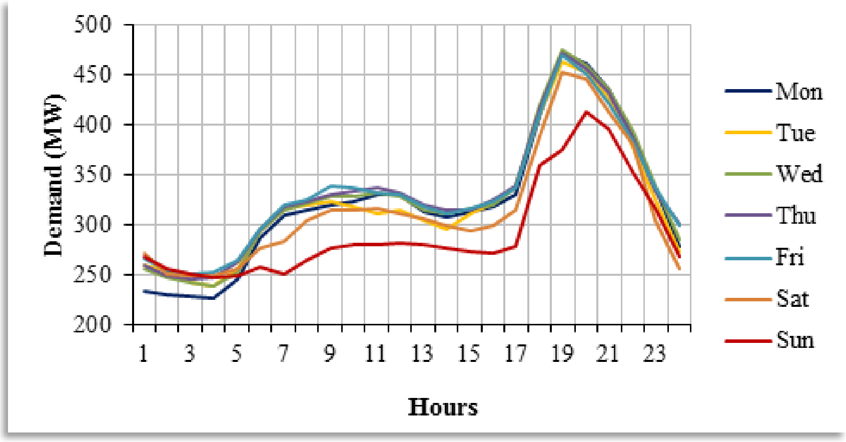

Figure 4.6 – Daily shape of peak demand in the EDM system in winter (data source: EDM)

Regarding parts of the day experiencing the same behaviour of demand, in summer, any day of the week shows three parts, while in winter, weekdays have three parts and Sunday/Holidays two parts. The length of those parts differs also for summer and winter and thus, there is a need of calculating the duration of each part. Thereby, in figure 4.7 is presented a sketch of the day's parts, in summer and winter and the table 4.2 summarizes the different values of share in demand for the seasons, type of days and parts of day.

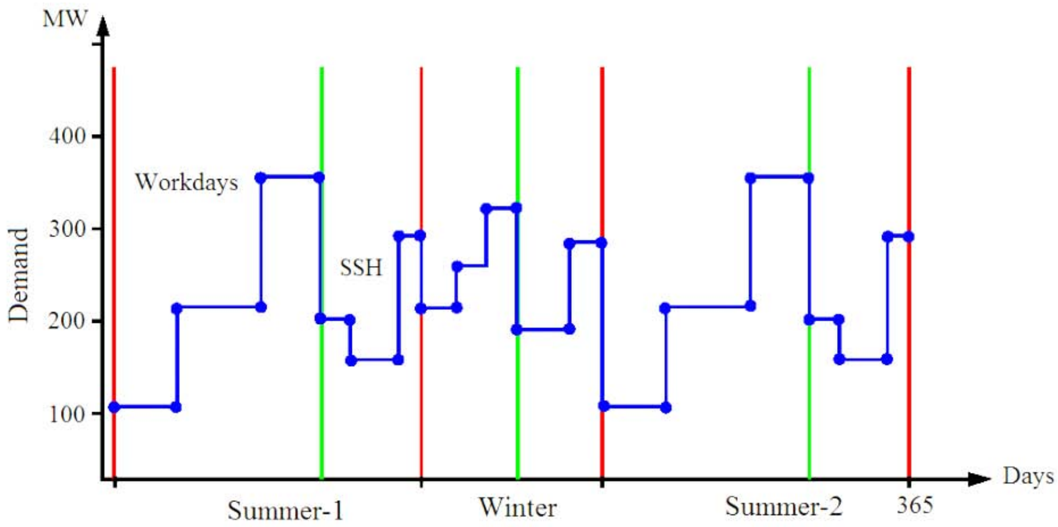

Figure 4.7 – Mozambique's sketch of annual load curve

Taking into account that total electricity consumed during the year 2010, estimated in 10237.3 GWh, represents the sum of electricity demand in both seasons, a percentage of share in demand was calculated and verified that summer accounts for 84.5% of total demand and winter the remaining percentage. Concerning demand share of the type of days, it was calculated looking at weekly demand in summer and winter and extracting the percentage of workdays and SSH demand. As result it was observed that workdays account for 71.4% and SSH for the remaining percentage.

Table 4.2 – Definition of seasonal variation of demand

Summer				
Parts of the day	**Duration (Hr)**	**Demand (MWh)**	**Demand (%)**	**Length (%)**
s1 of workdays	*23h – 7h*	*2464*	*0.285*	*0.333*
s2 of workdays	*7h – 18h*	*3938*	*0.456*	*0.458*
s3of workdays	*18h – 23h*	*2240*	*0.259*	*0.209*
s1 of SSH	*23h – 6h*	*2284*	*0.292*	*0.292*
s2 of SSH	*6h – 16h*	*3262*	*0.417*	*0.417*
s3 of SSH	*16h – 23h*	*2277*	*0.291*	*0.291*
Winter				
Parts of the day	**Duration (Hr)**	**Demand (MWh)**	**Demand (%)**	**Length (%)**
s1 of workdays	*22h – 6h*	*2505*	*0.32*	*0.333*
s2 of workdays	*6h – 17h*	*3522*	*0.45*	*0.458*
S3 of workdays	*17h – 22h*	*1800*	*0.23*	*0.209*
s1 of SSH	*23h – 17h*	*5132*	*0.73*	*0.75*
s2 of SSH	*17h – 23h*	*1897*	*0.27*	*0.25*

Most power plants, like other manufacturing facilities, process raw material into products (electricity in this case). Therefore, it is important to model the chain of energy forms, from resources to useful energy. When defining levels of energy form, special attention should be given to those which demand or supply varies with time. In this study, five levels of energy forms were defined as presented in the figure 4.8 and with electricity being the only commodity defined with load regions (load curve).

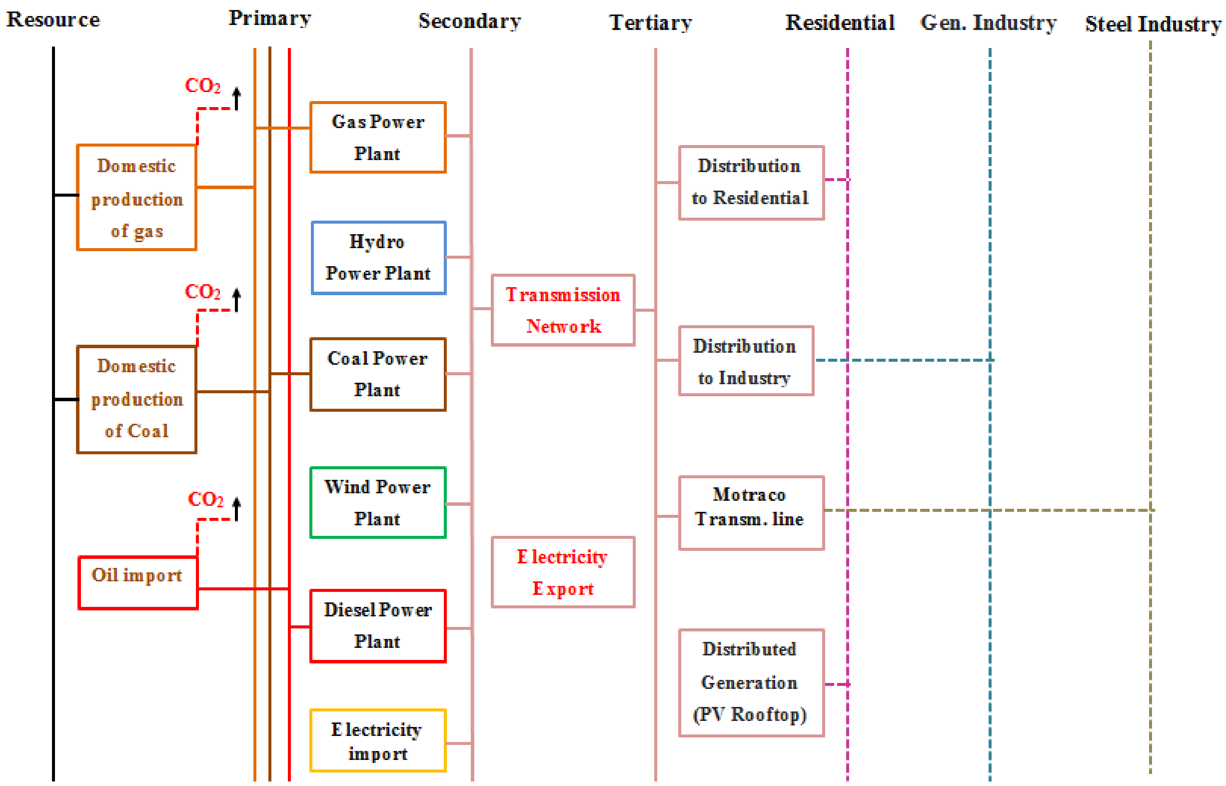

Figure 4.8 – Level of energy forms (adapted from MESSAGE user manual)

Costs represent investment for power plant construction, fuel acquisition, operation and maintenance. Tables 4.3 and 4.4 summarize investment costs, fixed and variable O&M costs and some technical parameters regarding existing and planned power plants. Efficiency was assumed at 35% for diesel power plants, 48% for gas and 37 % for coal power plants.

Table 4.3 – Technical parameters and costs of existing power plants (Source: IRENA, EDM)

	Capac.	**Investment Cost**	**Fixed O&M**	**Variable O&M**	**Dry CF**	**Average CF**
	MW	**$/kW**	**$/kW**	**$/MWh**	**%**	**%**
Hydro HCB	*2075*	*1876*	*8.72*	*1.51*	*66.2*	*84.2*
Hydro Mavuzi	*52*	*2456*	*8.72*	*1.51*	*54.5*	*72.5*
Hydro Chicamba	*38*	*2456*	*8.72*	*1.51*	*11.3*	*15.4*
Hydro Corrumana	*16*	*2456*	*8.72*	*1.51*	*10.5*	*20.4*
Gas Temane	*7*	*581*	*19.0*	*4.18*	*85.0*	*-*
Diesel	*65*	*1113*	*19.0*	*0.8*	*80.0*	*-*

Table 4.4 – Technical parameters and costs of planned power plants (Source: IRENA, EDM).

	Capac.	Investment Costs	Fixed O&M	Variable O&M	Dry CF	Average CF
	MW	$/kW	$/kW	$/MWh	%	%
Hydro HCB	*1245*	*1876*	*8.72*	*1.51*	*66.2*	*84.2*
Hydro M. Nkuwa	*1500*	*2118*	*8.72*	*1.51*	*63.7*	*79.6*
Hydro Boroma	*200*	*1730*	*8.72*	*1.51*	*63.7*	*79.6*
Hydro Lupata	*600*	*1730*	*8.72*	*1.51*	*58.0*	*73.8*
Hydro Ruo	*100*	*2517*	*8.72*	*1.51*	*58.0*	*73.8*
Hydro Lurio	*120*	*3750*	*8.72*	*1.51*	*58.0*	*73.8*
Hydro Malema	*60*	*2517*	*8.72*	*1.51*	*21.4*	*35.1*
Hydro Massingir	*27*	*1997*	*8.72*	*1.51*	*21.4*	*35.1*
Gas Kuvaninga	*60*	*1646*	*19.0*	*4.18*	*85.0*	-
Gas Maputo	*50*	*1714*	*19.0*	*4.18*	*85.0*	-
Gas Temane	*750*	*651*	*19.0*	*4.18*	*85.0*	-
Gas Aggreko	*230*	*1646*	*19.0*	*4.18*	*85.0*	-
Gas Moamba	*700*	*2080*	*19.0*	*4.18*	*85.0*	-
Coal Benga	*500*	*3025*	*20.0*	*0.96*	*88.0*	-
Coal Moatize	*600*	*2723*	*20.0*	*0.96*	*88.0*	-

Because most of new capacity additions have not yet entered in the stage of construction, first year of operation was assumed according to the length of construction period and information available as follow: gas power plant (2016), coal power plants (2018), hydropower (2019), solar PV (2015) and Wind power (2017).

When an unsuccessful start-up occurs a power plant might be forced to stay off line during a period of time. Similar to Nexante's report (2007), this probability that the unit will not be available for service when required is assumed to be 2% for hydro, solar PV and Wind power, while for thermal power plants is assumed to range between 5% to 7%. Commonly, FOR is expressed as:

$$FOR = \frac{FOH}{(FOH + SH)} 100\% \tag{4.19}$$

Where, FOH represents the forced outage hours and SH represents the service hours.

The planned outage rate (POR) is a parameter used to express a plant's unavailability due to scheduled outages planned well in advance. Similar to Nexante's report (2007), it is assumed to be 5 % for hydro, solar PV and wind power plants, while for thermal is assumed to vary from 7% to 15%. Generally, POR is expressed as:

$$POR = \frac{POH}{(PH)} 100\% \tag{4.20}$$

Where, POH represents the planned outage hours and PH is the period hours.

In thermal plants, capacity factor (CF) can be estimated taking into account forced outage rate and planned outage rate by the expression:

$$CF = (1 - POR) \cdot (1 - FOR) \tag{4.21}$$

In MESSAGE, forced outage rate for dispatchable technologies can be approximated by a parameter called plant factor (PF) which allows the user to de-rate the capacity of a generating technology. The PF for dispatchable technologies is set to:

$$PF = 1 - FOR \tag{4.22}$$

In the case of non-dispatchable technologies such as solar PV and wind power PF = CF.

In MESSAGE, planned outage rate can be approximated by operation time OP_T, where

OP_T = POR.

$$CF = PF \cdot OP_T \tag{4.23}$$

So for non-dispatchable technologies, OP_T is set to 1.

Fossil fuel, in solid, liquid and gaseous form, represents by far the largest source of energy used to generate electricity. The products of combustion consist of fuel gases and solid residual from combustion of solid fuels. The products of complete combustion of a fuel contain CO_2, H_2O (water vapour), SO_2, N_2 and O_2. When the incomplete combustion occurs, the flue gas also contains CO and unburned hydrocarbons (Khartchenko, 1998: 19).

Considering that the sustainability of using fossil fuel in the power sector of Mozambique is one of the main objectives of the study, the model set constraints regarding emission per unit of electricity generation from gas and coal power plant. According to IEA (2012: 41), CO_2 emissions per kWh of electricity generation from coal and natural gas are estimated in 0.9 kg and 0.4 kg respectively.

Regarding water availability, for hydropower, a “dry year” capacity factor is assumed in all years, conservatively. Regarding fuel, Mozambique’s coal and natural gas reserves are estimated in 6 billion tonnes and 180 TCF respectively and prices are estimated to be 2 USD/GJ for coal, 8 USD/GJ for gas and 22 USD/GJ for diesel (IRENA, 2013: 22) with an expected increase.

According to IEA (2013: 45), the world is experiencing a period of historically high fuel prices. This has generated responses on the demand and supply sides in improving energy efficiency. In that context, taking into account IEA’s projected fuel price, it was assumed that coal price is expected to increase 1.2% per year, natural gas 0.5% per year and diesel 0.9% per year, with the low growth rate of natural gas price justified by the recent discoveries of huge reserves in the northern region of the country in line with new sources of gas, both conventional and unconventional, that bring additional diversity to global supply.

On the other hand there have always been differences in natural gas prices across the major markets worldwide. For example, in 2012, average natural gas prices in the United States were less than one-quarter of the prices in Europe and one-sixth of those in Japan. This low increase in natural gas price is also linked with the incentives to expand natural gas usage into new areas such as transport (IEA 2013: 46).

In MESSAGE, the total installed capacity of generating technologies is solved for each time step in order to keep energy balance and to ensure that the supply power is always greater than the power demands in each time slice, subject to limits on new capacity additions or limits on total installed capacity for example to capture committed future projects of power generation.

Considering that an excess “operational” capacity needs to be installed over and above peak demand requirements for ensuring a certain level of reliability for the power system, reserve margin constraint of 10% has been imposed on both scenarios. For the Mozambican power system, reserve margin of 10% was also used by IRENA, since the power sector is still undeveloped and does not have enough capacity to increase suddenly the reserve margin up to international standards. Generally, 15% of reserve margin is often used for more developed systems. Reserve margin is defined as the difference between the operable capacity and the peak demand for a particular year as a percentage of peak demand and is expressed as:

$$\sum_{i=1}^{n} \alpha(i) C_p(i) \geq (1 + RM) D_{peak} \tag{4.24}$$

Where:

$\alpha(i)$ - represents the capacity credit given to power plant (i) or share of capacity that is accounted as “firm” (a fraction or percentage);

$C_p(i)$ - is the capacity of the power plant (i) in MW (centralized only);

RM - is the reserve margin (in this study RM=10%); and

D_{peak} - is the peak demand on the centralised grid system in MW.

The share of capacity that is considered firm is set to “one” for dispatchable technologies such as thermal and hydro power with dams, while for intermittent renewable power technologies, the capacity credit depends on the share of their total capacity in a power system and the quality of the intermittent resource. As intermittent renewable technologies cannot be relied upon to generate power at any given time due to the variability of wind and solar conditions, generally, capacity credit is lower than the availability factor.

Thereby, over the period of study, depending on the demand, MESSAGE will estimate progressively not only the necessary power output for each period but also, the ideal year to add new additional capacity. The main task of the study, seeks to find the optimal investments in generation capacity of electricity in Mozambique with the help of MESSAGE.

CHAPTER 5 – RESULTS AND DISCUSSION

5.1. Analysis and interpretation

The approach of using scenarios to analyse energy trends has find wide application in demand and supply forecasts worldwide. Historical data on economic and energy variables represents a starting point for the energy modelling approach. Given this, the main assumptions are related to economic growth, demographic variation and aspirations around electricity expansion.

Considering rates of population and GDP growth assumed and predicted increase in access to electricity, country's population and GDP are projected. The analysis and interpretation of the results were assessed by comparing the economic and development characteristics of some SADC countries, mainly South Africa. The comparison with South Africa was chosen because is one of the most developed countries in the SADC region and worldwide in several aspects analyzed in the study.

Figure 5.1 shows that Mozambique's population will increase from 21.85 million people in 2010 to 42.38 million people in 2040 in the Borderline scenario. Regarding the Optimistic scenario, in 2040, the projected population will be approximately 50 million people, a prediction close to the estimated population of both South Africa and Tanzania in 2012.

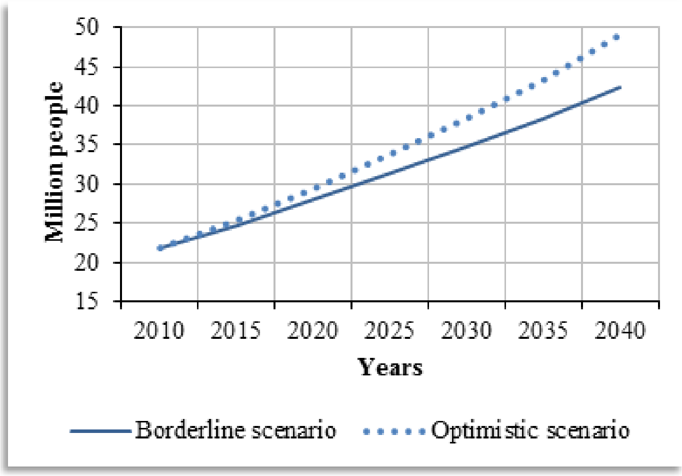

Figure 5.1 – Mozambique's projected population

With respect to GDP, in an Optimistic scenario, it is expected that GDP will increase from 9.99 Billion USD in 2010 to about 46.0 Billion USD in 2040, representing approximately 40% of Angola's GDP in 2012. Considering that activity in Mozambique has stabilized in the last decade supported by policies and renewed confidence, the predicted GDP is not far from the possibilities of the country. According to the World Bank (2011), Mozambique's macroeconomic performance has been generally good or improving when measured by aggregate indicators such as growth, inflation, balance of payments, external debt, and the budget.

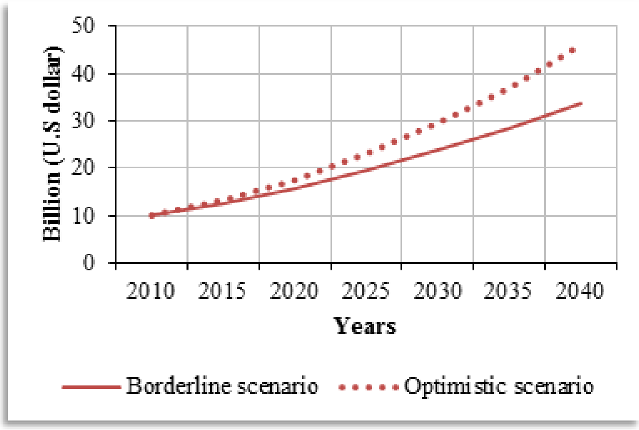

Figure 5.2 – Mozambique's projected GDP

5.2. Demand side analysis

Demand analysis involves the assessment of factors which influence demand such number of customers, potential economic development opportunities and electricity grid expansion. Information derived is useful for forecasting demand, a key element of the plan (khalema-rebedy et al 1998). Taking into account Mozambique's total number of households and percentage of access to electricity, figure 5.3 presents projected electrified households within the period of study.

As it is observed, electrified households will increase from 0.9 million in 2010 to 9.2 million in 2040 in the Optimistic scenario. Comparing with South Africa's electrified household in 2012, estimated in 9.8 million, this achievement could represent a huge jump in the lifestyle of the Mozambican population, since access to electricity by urban and rural households could be considered an indicator of development and has become a core priority of the state.

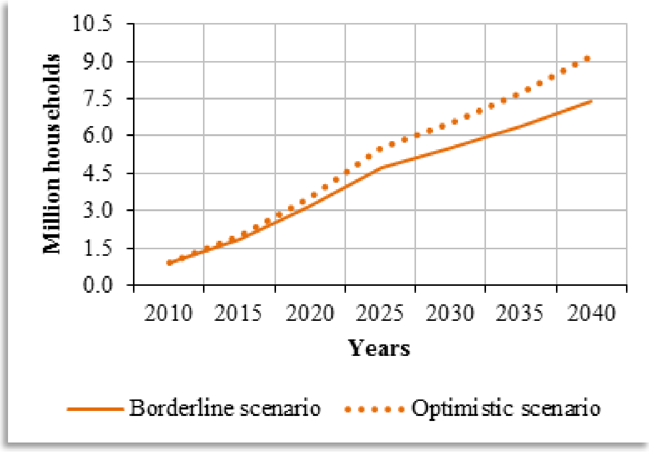

Figure 5.3 – Mozambique's electrified households

Although Mozambique's total energy intensity has been growing in the last decade in all demand sectors, historical data shows that the average consumption in the residential sector has decreased. This is explained by the fact that currently, the low consumption households (Lhh) has been accounting for the largest share of customers in the residential sector, since most of new connections are related to this type of residential consumers.

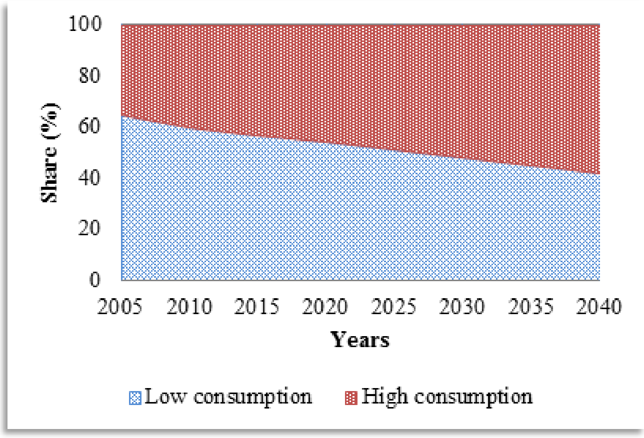

Figure 5.4 – Share of total connection in the Optimistic scenario

Nevertheless, it is understood that the tendency of the low consumers to constitute the majority will change with potential economic development opportunities, growth of GDP per capita and access to electricity. There has always been a tight coupling between energy use and economic growth. Demand for electricity has always displayed good correlation with economic growth (Khatib 1997: 11). Therefore, a portion of the low consumers will shift to the high consumers as is shown in figure 5.4.

Assuming the capital Maputo's average residential consumption as the higher, the annual average electricity (kWh) consumption in the low consumption households was calculated from the historical data, where a downward trend followed by a turning point was noted in both categories of households. In order to generate the projection for the residential sector, the model used an elasticity linking electricity intensity to GDP per capita equal to 1, meaning that average electricity consumption in the residential sector grows at the same rhythm as GDP per capita.

$$\overline{kWh_t} = \overline{kWh_{t_0}} \cdot (1 + \lambda \cdot \varepsilon)^{t-t_0} \qquad (5.1)$$

Where:

kWh_t - is the average electricity consumption per household in the year projected;

kWh_{t_0} - is the average electricity consumption per household in the present year;

ε - is the elasticity;

λ - is the growth rate of GDP per capita.

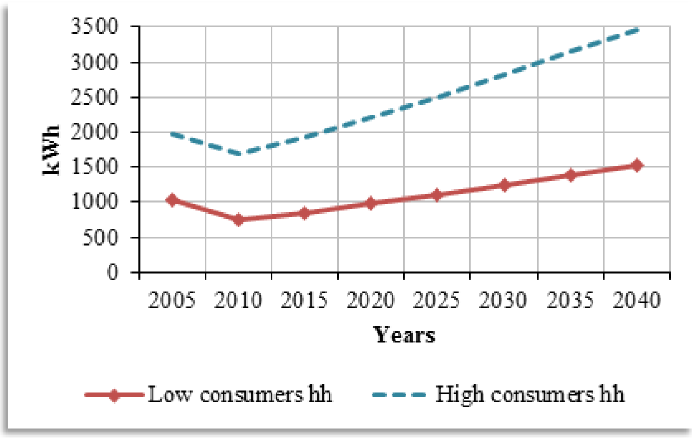

Figure 5.5 – Average annual consumption per residential categories in the Optimistic scenario

As it is noted in figure 5.5 representing the Optimistic scenario, historical data showed that electricity consumption in the residential sector dropped between 2005 and 2010, due to fast increase in new connections in the districts and suburbs where electricity consumption is lower and thus, affected the overall average consumption. From the base year of the model annual electricity consumption in the low consumption households, it is expected to increase from 746.5 kWh in 2010 to 1529.4 kWh in 2040, while in the high consumption households, increases from 1690 kWh in 2010 to 3462.3 kWh in 2040. Currently, the rural areas which account for the largest number of low consumption households, electricity is used mainly for lighting and also for television and radio.

The total electricity intensity (GWh) in the residential sector is modelled as:

$$GWh_t = \frac{Hhh_t \cdot \overline{kWh}_{Hhht} + Lhh_x \cdot \overline{kWh}_{Lhht}}{10^6} \tag{5.2}$$

Where:

$$Hhh = E_{HH} \cdot \%Hhh$$

$$Lhh = E_{HH} \cdot \%Lhh$$

Here, *Ehh* represents the total electrified households, while *% Hhh* and *% Lhh* is the percentage of the residential categories share in the year projected.

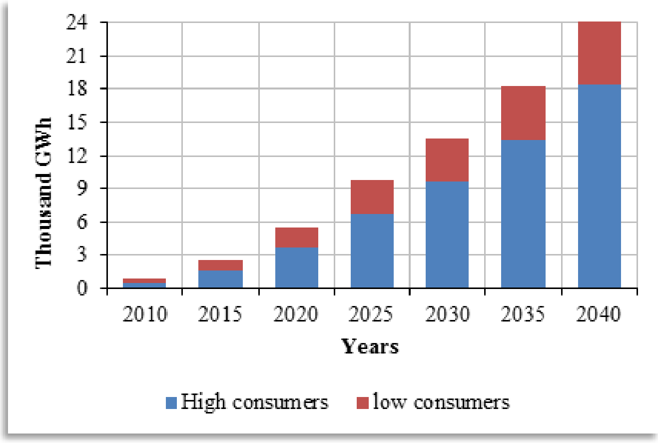

Figure 5.6 – Residential sector's electricity demand in the Optimistic scenario

In 2000, South Africa's residential sector was estimated at about 7.7 million customers (DoE, 2012: 6) and its consumption at about 30 thousand GWh (Winkler, 2006: 43), meaning an average consumption of 3896 kWh per household. In 2040, the projections in the Optimistic scenario show Mozambique's residential sector of about 9.2 thousand customers, and a consumption of 24.33 Terawatt-hour (TWh), meaning an average consumption of 2689 kWh per household (figure 5.6). Given that South Africa has always been considered a developed country even in 2000, the numbers showing the evolution of Mozambique's residential sector lifestyle seem reasonable.

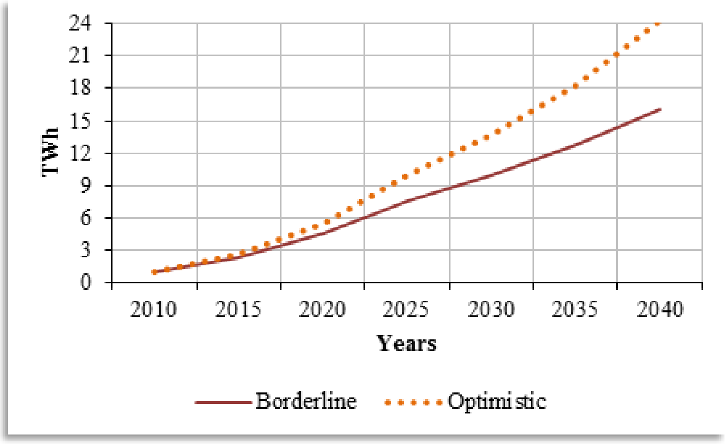

Figure 5.7– Residential sector's consumption by scenario

Regarding the economic sectors, agriculture, commerce and industry the demand modelling analysis applied the concept of elasticity demand linking electricity consumption per sector with the total GDP of the country. Growth rates for electricity consumption and economic output (approximated by GDP growth rates) have been roughly correlated in the Winkler's study (2006: 35), focused on energy policies for sustainable development in South Africa. First, from historical data, kWh per U.S. Dollar in each sector was calculated dividing the consumption by the sector's GDP. Then, the elasticity of demand was estimated dividing the variation of consumption by the variation of country's GDP.

Table 5.1 – Estimation of kWh/USD by economic sectors

kWh per U. S. Dollar						
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
Commercial	*0.056*	*0.059*	*0.059*	*0.050*	*0.060*	*0.054*
Agriculture	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.00011*
Manufacturing	*0.542*	*0.453*	*0.493*	*0.486*	*0.528*	*0.566*
Electricity	*0.146*	*0.144*	*0.119*	*0.093*	*0.101*	*0.098*
Steel	*16.481*	*14.979*	*14.471*	*14.017*	*14.139*	*13.014*
Mining	*0.504*	*0.422*	*0.534*	*0.462*	*0.497*	*0.472*

Considering that global energy consumption has grown at a much faster rate than GDP, where the coefficient of elasticity is a large number, elasticity was assumed equal to unity (increase in quantity demanded is accompanied by same proportionate increase in GDP) in order to avoid a sharp increase of GDP that could be unrealistic. Thereby, the year kWh/U.S. Dollar per economic sector is projected as:

$$kWh/\$_t = kWh/\$_{t_0} \cdot (1 + \alpha \cdot \varepsilon)^{t-t_0} \tag{5.3}$$

Where:

$kWh/\$_t$ - is the ratio electricity consumption/GDP sector in the year projected;

ε - is the elasticity;

α - is the growth rate of country's GDP.

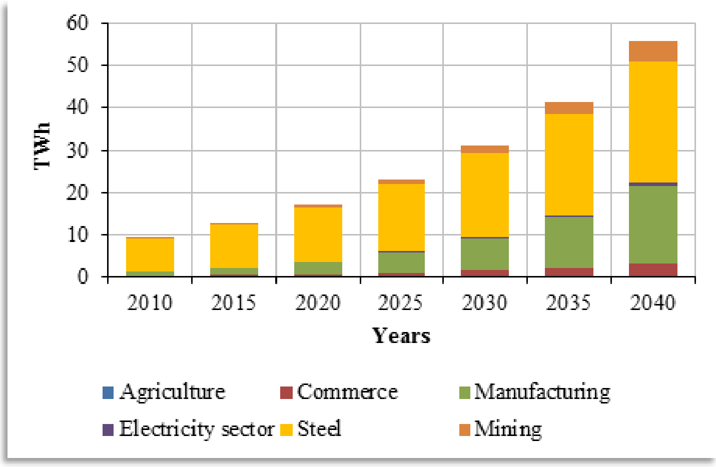

Figure 5.8 – Mozambique's electricity consumption per economic activity in the Optimistic scenario

In figure 5.8 it can be observed that Mozambique's electricity consumption in the future will be dominated by the manufacturing and steel sectors and thus, manufacturing will become the biggest driver of growth in electricity demand in the economy, since this sector is also intrinsically linked to other through transformation and processing of various products.

Similarly, according to Statistics South Africa (2012) the growth of South Africa's manufacturing sector is driven by strong growth in the production of petroleum, chemical products, wood products, metal and nonferrous metal products, and nonmetallic mineral products. Manufacturing accounts for the largest consumption of electricity in South Africa and this sector is also a major contributor to economic growth and exports (Winkler, 2006: 43).

Although the agriculture and commercial sectors contribute significantly to the country's GDP, Mozambique's current policy centred on the export of unprocessed products in the agriculture and mining sector constitute the main reason of the low rates of electricity consumption in these sectors. A change of strategy would enable other sectors to benefit from the incomes of these sectors, since for example; the commercial sector could not only diversify the range of products but also, sell them at higher prices.

The low rate of electricity consumption in the agricultural sector is a common feature not only in developing countries but also in developed countries. In South Africa, agriculture sector accounts for approximately 2.3% of total electricity demand (Davidson & Mwakasonda, 2003: 12, Winkler, 2006: 40,). Given this, Mozambique's agriculture sector will also continue consuming electricity less than other sectors.

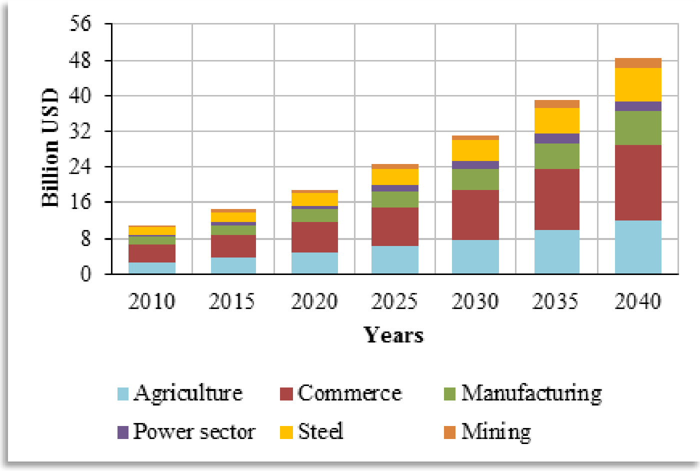

Figure 5.9 – Mozambique's GDP by economic activity in the Optimistic scenario

Analysing the country's total electricity consumption (figure 5.10) it is noted that in the perspective of an Optimistic development, electricity demand will grow from 10 TWh in 2010 to 80 TWh in 2040. This electricity consumption represents almost one third of South Africa's current consumption, estimated at 250 thousand GWh. In that year (2040), the industrial sector will account for 65% of the total electricity consumption while the residential will represent 30%. The remaining percentage represents the consumption of the commercial and agricultural sector, but with a very little share of the last one (approximately 1%).

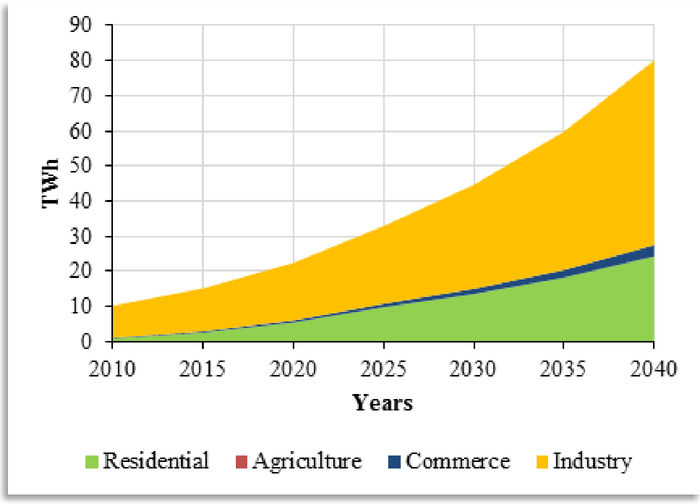

Figure 5.10 – Mozambique's total electricity consumption in the Optimistic scenario

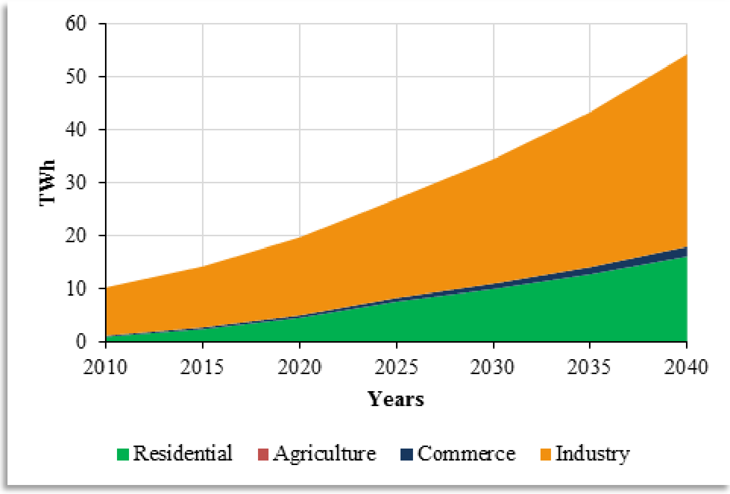

Figure 5.11 – Mozambique's total electricity consumption in the Borderline scenario

5.3. Supply side analysis

Supply analysis looks at how demand can be met economically given the existing power generation plants, resources potential, technology availability and advancement, and supply options. Supply analysis conclusions help to determine the scope for system expansion planning (khalema-rebedy et al 1998). In 2010, Mozambique's total operational capacity of power generation was estimated to be 2179 MW of hydropower, 7 MW of gas power plant and 65 MW of diesel power. It is interesting to note that although a large share of the electricity produced by HCB is exported to South Africa and other countries of the region, part of the electricity necessary to meet the demand in the country is imported from Eskom.

Mozambique imports electricity from Eskom because during the construction of the Cahora Bassa Hydropower station by the Portuguese government, South African Governments were also involved and an agreement was signed, stating that Portugal would build and operate the power plant together with the high-voltage direct current (HVDC) transmission system required to bring electricity to the border of South Africa.

On the other hand, South Africa, undertook to build and operate the Apollo converter station and part of the transmission system required to bring the electricity from the Mozambican/South Africa border to the Apollo converter station near Midrand. South Africa was then obliged to buy electricity that Portugal was obliged to supply (HCB). In that context, most of the electricity produced by HCB is converted in South Africa and sold to this country.

5.3.1. The optimization analysis

In order to satisfy the projected demand in both the Borderline and Optimistic scenarios, the supply model was developed taking into account data collected and the main assumption presented in the section 4.3.2. The objective function of the model is to optimize power output taking into account investment costs, fixed and variable O&M and fuel costs. The economic merit of each generating unit is dependent not only on cost, but also on capacity factor, and efficiency.

The levelized cost of generating electricity (LCOE) in the year 2011 given the assumptions in the section 4.4.1 is presented in figure 5.12. As is observed, because of its high cost of fuel, diesel technology represents the most expensive technology in terms of levelized costs followed by gas. Regarding hydro and coal technologies, levelized cost depends on investment costs and usually are lowest than levelized costs of other technologies. In relation to solar PV and wind technologies, their levelized costs are influenced by the low capacity factor which makes these technologies less competitive.

Depending on the characteristics of power plant operation, the costs of power system operation can vary substantially. If all generation equipment that is online for the peak hour would remain online for the entire day, then many of these units would be operating at their minimum power limits during the early morning. Consequently, economic decisions must be made, regarding selection of units to be shut down, the hour of the day they are to be shut down and the hour of the following day that they are to be started up again (Stoll, 1989: 410).

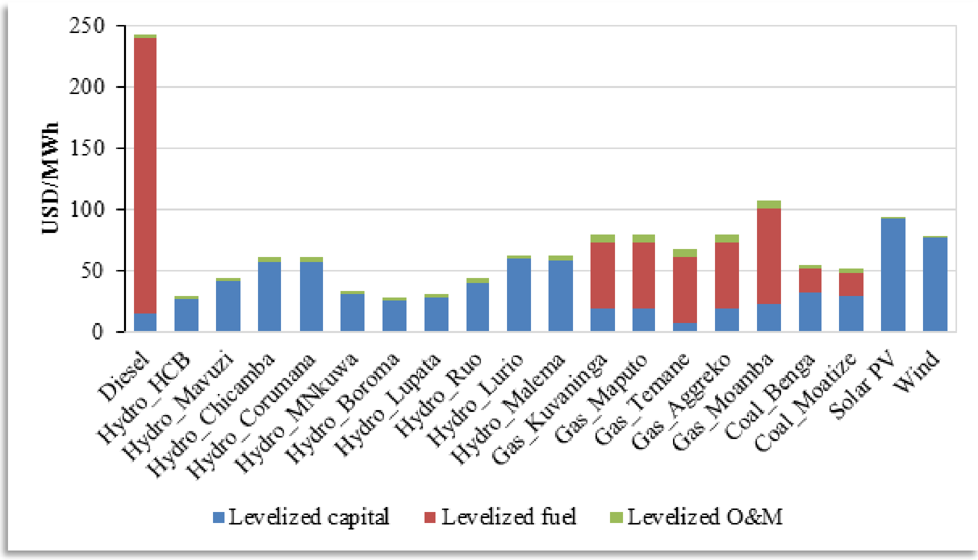

Figure 5.12 – Levelezed cost by power plant in the year 2011 by technology

Two expansion plans were computed using MESSAGE, aiming to find the optimal power generation mix and new capacity addition regarding power projects. There is currently an estimated 6742 MW[4] of projects under consideration. The results showed that in the Borderline scenario, 4976.6 MW of planned capacity addition and 185 MW of no planned capacity addition were added.

As it is shown in figure 5.13, the expansion plan begins in 2011, with the addition of 107 MW of gas technology (Aggreko power plant) and its expansion in 2012, with the addition of 120 MW. It is important to note that, the Aggreko gas power plant began to operate in 2012, supplying electricity to South Africa and Mozambique and in 2013, its

[4] Gas generic, coal generic, solar and wind power are not included in this estimated capacity addition, since are considered no approved power generation projects.

capacity was expanded from 107 MW to 230 MW in order to supply power to Namibia and Mozambique.

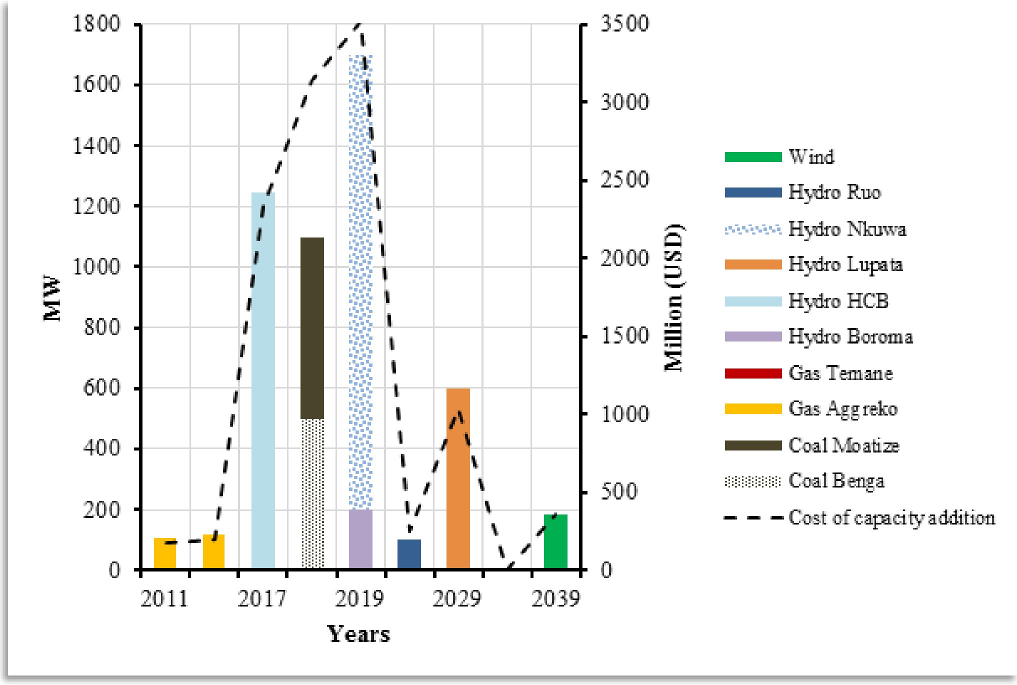

Figure 5.13 – New annual capacity addition and costs in the Borderline scenario

Additional capacity of hydropower technology, takes place at Cahora Bassa dam in 2017, increasing total installed capacity of this power plant from 2075 to 3320 MW. Considering that the HCB north bank will share infrastructures with the south bank, it is a wise strategy to start adding new capacity to this existing dam, since investment costs are lower than those needed to build new hydro power facility and construction time required is also lower. The Benga (500 MW) and the Moatize (600 MW) coal technology are added in 2018, followed by the addition of Nphanda Nkuwa (1500 MW) and the Boroma (200 MW) hydro power plants in 2019.

The years 2021 and 2029 are characterized by the addition of complementary hydropower technology, the Ruo (100 MW) and the Lupata (600 MW) respectively. Finally, the expansion plan is completed with the addition of gas technology, specifically, the temane gas power plant (4.6 MW) in 2034 and wind technology (185 MW) in 2039. With this capacity addition, installed capacity increases from 2358 MW in 2011 to approximately 7348 MW in 2040 after excluding retired capacity.

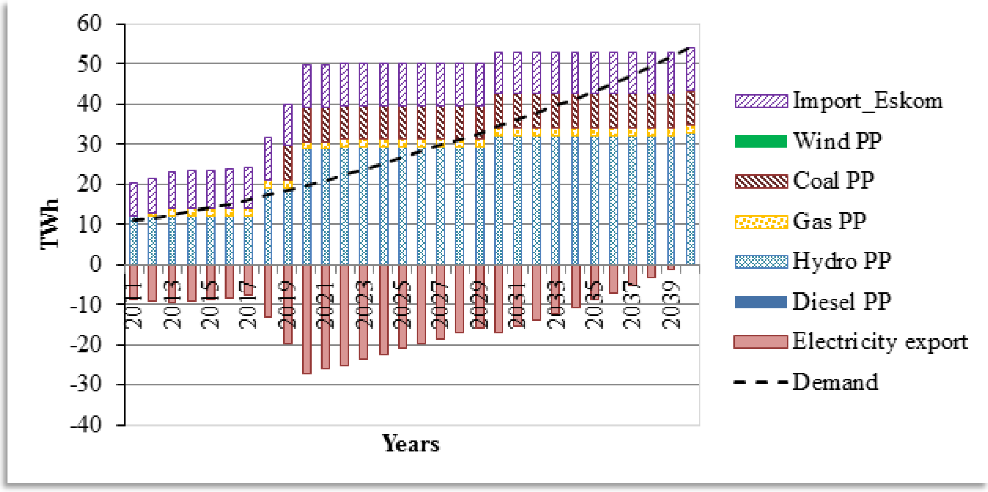

Figure 5.14 – Electricity generation, demand and exports in the Borderline scenario

In the Borderline scenario, electricity generated is expected to rise from 12.4 TWh in 2011 to 43.9 TWh in 2040. Taking into account electricity imported from Eskom, electricity available for distribution rises from 20.6 TWh in 2011 to 53.3 TWh in 2040 as it is presented in figure 5.14. Compared to South Africa's total volume of electricity available for distribution in 2012, estimated in 23.4 TWh this electricity represents only 23% (SSA, 2012).

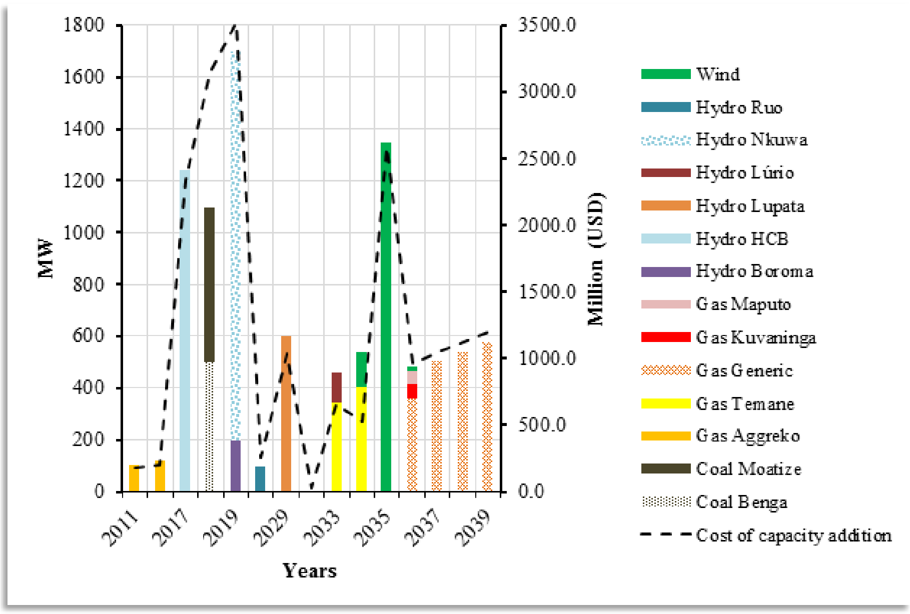

Figure 5.15 – New annual capacity addition and costs in the Optimistic scenario

In the Optimistic scenario, the results showed that, 5842 MW of committed capacity addition and 3589 MW of non-committed capacity addition were made (figure 5.15).

Equally to the Borderline scenario, the expansion plan begins in 2011, with the addition of 107 MW of gas technology (Aggreko) and its expansion in 2012, with the addition of 120 MW and then HCB is expanded in 2017 from 2075 to 3320 MW. In 2018 the first coal power plants of Mozambique are installed, with the addition of the Benga (500 MW) and the Moatize (600 MW) coal power plants. Coal plays an essential role in global energy mix, particularly for power generation, but it is important to use it efficiently and reduce its environmental footprint (IEA, 2010a: 5). The Mpanda Nkuwa (1500 MW) and the Boroma (200 MW) hydro power plants are added in 2019, followed by the Ruo hydro power (100 MW) in 2021.

In 2029, the Lupata hydro power (600 MW) starts to operate followed by the addition of the Lúrio hydro power (120 MW) in 2033. At the same time, 346.5 MW of gas technology are added at Temane gas power plant. Considering that the new capacity of the Temane gas power plant will be 750 MW, the second phase is completed in 2034 with the addition of 403.5 MW followed by the addition of 135.6 MW of wind technology in 2035. Since Mozambique´s wind capacity is estimated in 1500 MW, subsequent additions of wind technology occur in 2036 (1349.2 MW) and 2037 (15.2 MW). At the same time, 358 MW of gas generic[5] are added alongside with the addition of the Maputo (50 MW) and the Kuvaninga (60 MW) gas power plants.

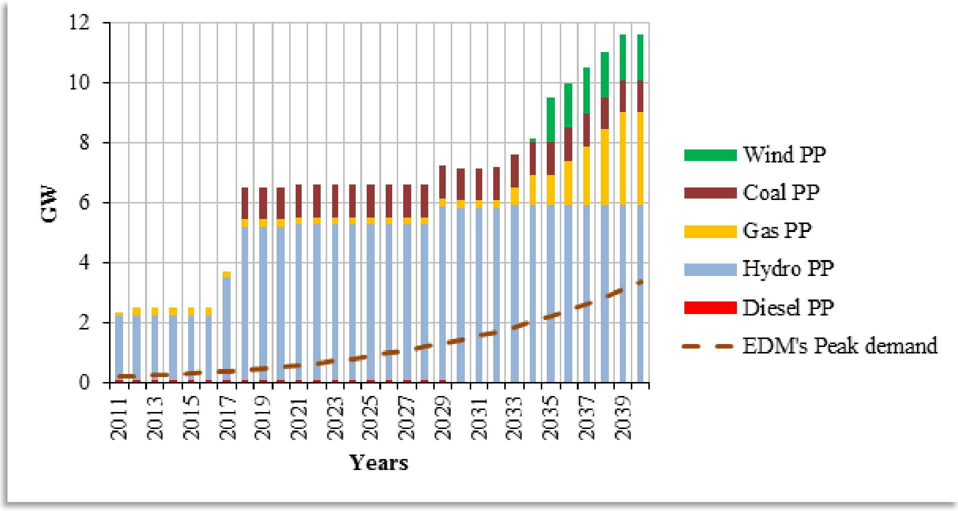

Figure 5.16 – Total installed capacity and system peak in the Optimistic scenario

[5]Gas generic is a designation given to possible new gas power project which are not yet identified. For example, could represent the emerging of new gas power plant in the northern region, where gas has been discovered recently.

Finally, the expansion plan is completed, with the implementation of other gas generic power plants in 2037 (505.3 MW), 2038 (539.4 MW) and 2039 (575.9 MW). After completing the expansion plan, total installed capacity increases from 2358 MW in 2011 to 11600 MW in 2040 after excluding retired capacity as it is illustrated in figure 5.16.

As result, power generation increases from 12.4 TWh in 2011 to 69.7 TWh in 2040. Taking into account electricity imported from Eskom, electricity available for distribution rises from 20.6 TWh in 2011 to 80.2 TWh in 2040 as is presented in the figure 5.17. Comparing with South Africa's total volume of electricity available for distribution in 2012, this electricity represents only 34.21% (SSA, 2012).

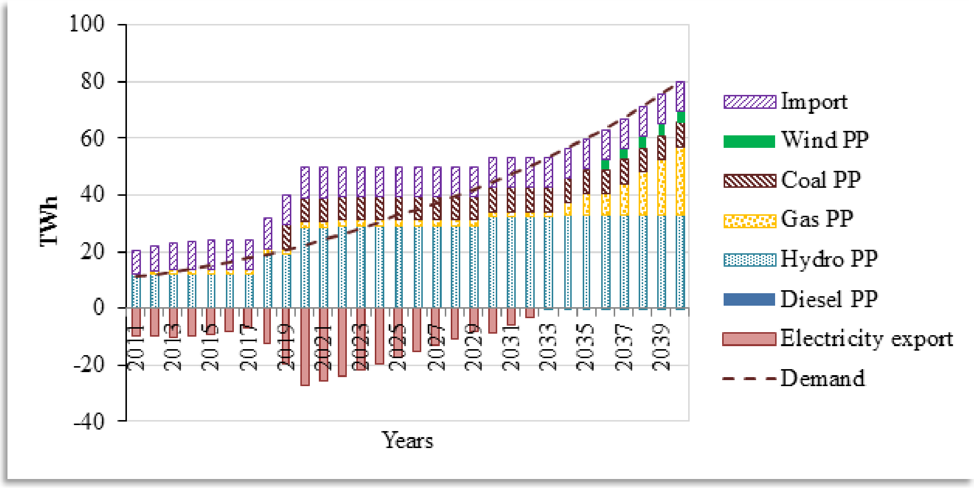

Figure 5.17 – Electricity available, demand and export in the Optimistic scenario

As it is observed, electricity import from Eskom will continue covering the shortage of electricity in Mozambique as a result of the agreement between power utilities (Eskom, EDM and MOTRACO). As previously referenced in this study, almost all imported electricity is consumed by MOZAL.

Similarly, Mozambique will continue exporting electricity to other SADC countries integrated in the SAPP agreement. As it is observed in figure 5.18, electricity export increases rapidly from 2017 to 2020 as result of electricity production from new power plants, specifically HCB north bank, Benga, Moatize, Mpanda Nkuwa and Boroma. However, because electricity demand also increases with the growth of economy and other development variables, after 2020, electricity export will decrease, since new capacities addition tends to cover internal demand. In the future, in case of expansion, it is expected that MOZAL, will consume internal electricity, since Mozambique's power generation capacity will increase. Therefore, it is not expected that the volume of electricity imports will grow.

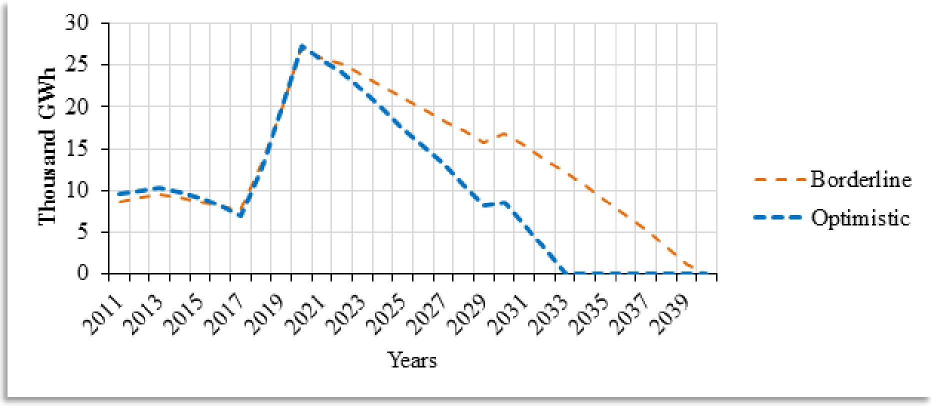

Figure 5.18 – Electricity export to SADC region

5.3.2. Risks and uncertainties of power system evaluation

From a practical point view any project is subjected to risks and uncertainties. In the power supply planning process, risks and uncertainties analysis enables more accurate evaluation of economic and technology supply options. Sensitivity analysis techniques are carried out practically during every financial and economic evaluation and assist to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. It is an assessment of the influence which variations in the selected project inputs, can have on the project's output (Khatib 1997: 154).

In this study, first of all, the Optimistic scenario was selected as the proposed expansion plan, since in terms of outcomes, the scenario presents Mozambique´s development aspirations, such as GDP growth, electricity demand and production and an expansion plan comprising a diversified mix of technologies. Considering this scenario as reference, sensitivity analysis was carried out in order to identify changes in supply option varying some input variables.

First of all, solar PV technology was shifted from in-grid system to roof-top, because the first results showed that solar PV technology is not competitive when connected in grid with other technologies (hydro, coal and gas technologies) because of its lower capacity factor and non-dispatchability. This sensitivity analysis showed that the new scenario called Optimistic PV roof-top presented capacity addition of solar PV (771.9 MW in 2038 and 816.3 MW in 2039), but without changing the structure of capacity addition regarding other technologies compared with the Optimistic reference scenario.

The Model's addition of solar PV roof-top can be justified by the fact that solar PV on roof-top is not subjected to constraints such as despatchable features or losses in transmission lines. Thereby, while in the Optimistic reference scenario, total installed capacity increased from 2358 MW to 11610 MW in 2040, in the Optimistic solar PV roof-top, total installed capacity increased to approximately 13199 MW in 2040.

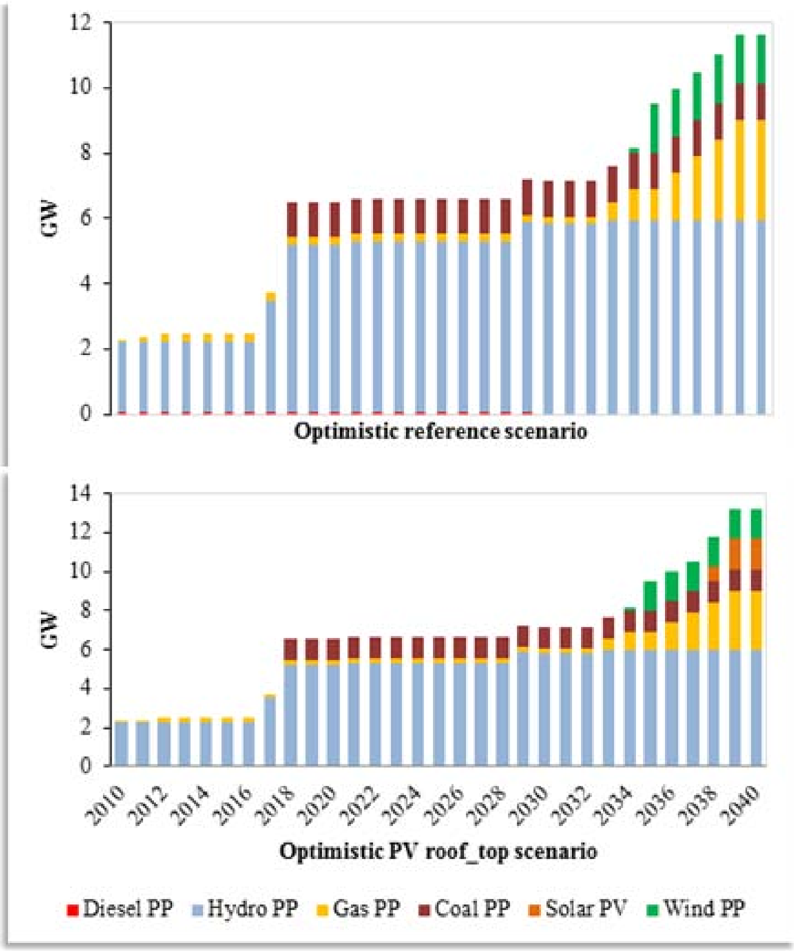

Figure 5.19 – Comparison of installed capacity in the first sensitive analysis

Secondly, sensitivity analysis on the investment costs of hydropower was carried out assuming that all new hydropower projects have the same investment cost, equal to 2500 USD/kW, since collected information presents a notable difference in hydropower investment costs, and could perhaps be in some case over-optimistic given the costs identified for some more recent projects. For example, regarding the Lúrio hydro power station, IRENA estimates an investment cost of about 2000 USD/kW while EDM estimates an investment of 3300 USD/kW. On the other hand, EDM presents an investment cost of 1200 USD/kW for the Nphanda Nkuwa hydro power while IRENA presents 1650 UDS/kW.

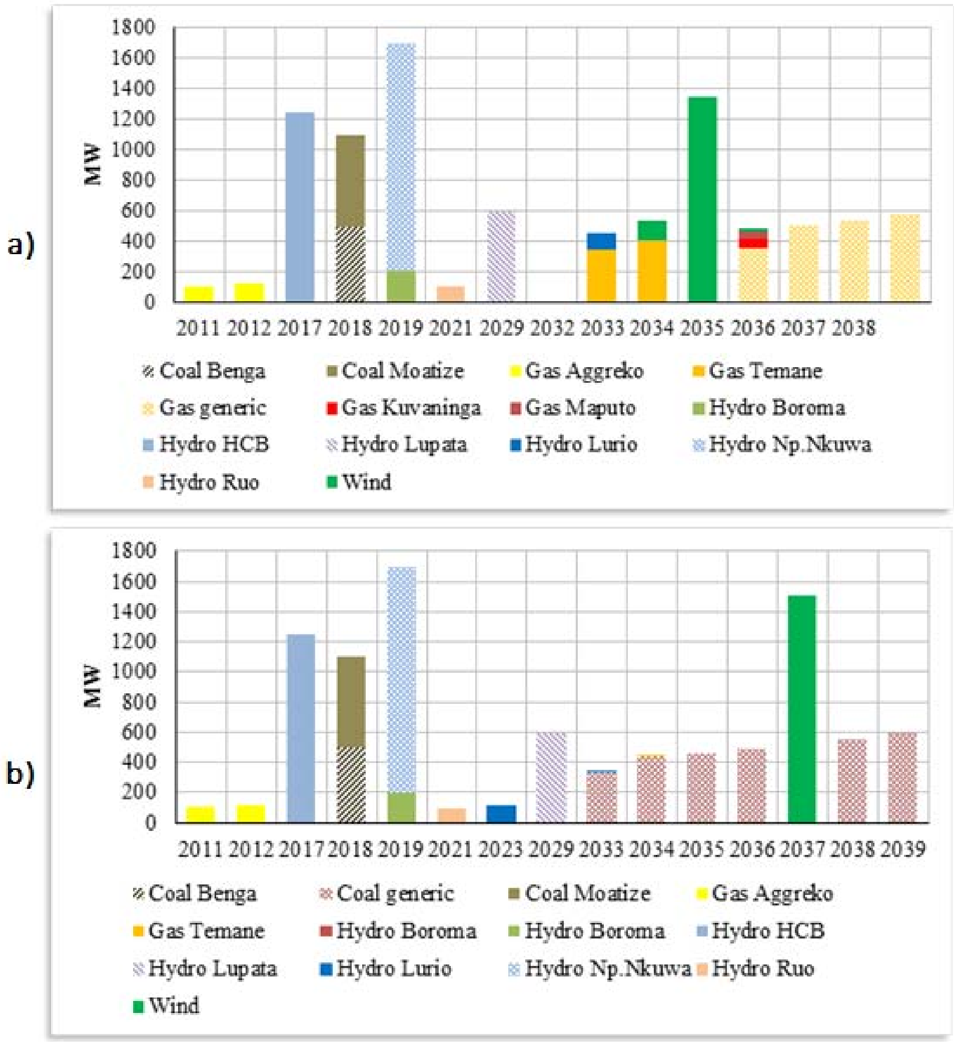

Figure 5.20 – Comparison of installed capacity in the Optimistic and hydro-capital scenarios

As a result of the second sensitivity analysis, the new scenario called Optimistic hydro-capital presented small changes regarding capacity addition of hydro power technology and considerable changes regarding fossil fuel technologies (coal and gas). As can be observed in figure 5.20, in the Optimistic reference scenario (a), capacity addition of the Lúrio hydro power plant occurs in 2033, while in the Optimistic hydro-capital scenario (b) occurs in 2023. The early addition of Lúrio hydro power is related to the decrease in its investment cost from 3750 USD/kW in the Optimistic scenario to 2500 USD/kw in the Optimistic hydro-capital scenario.

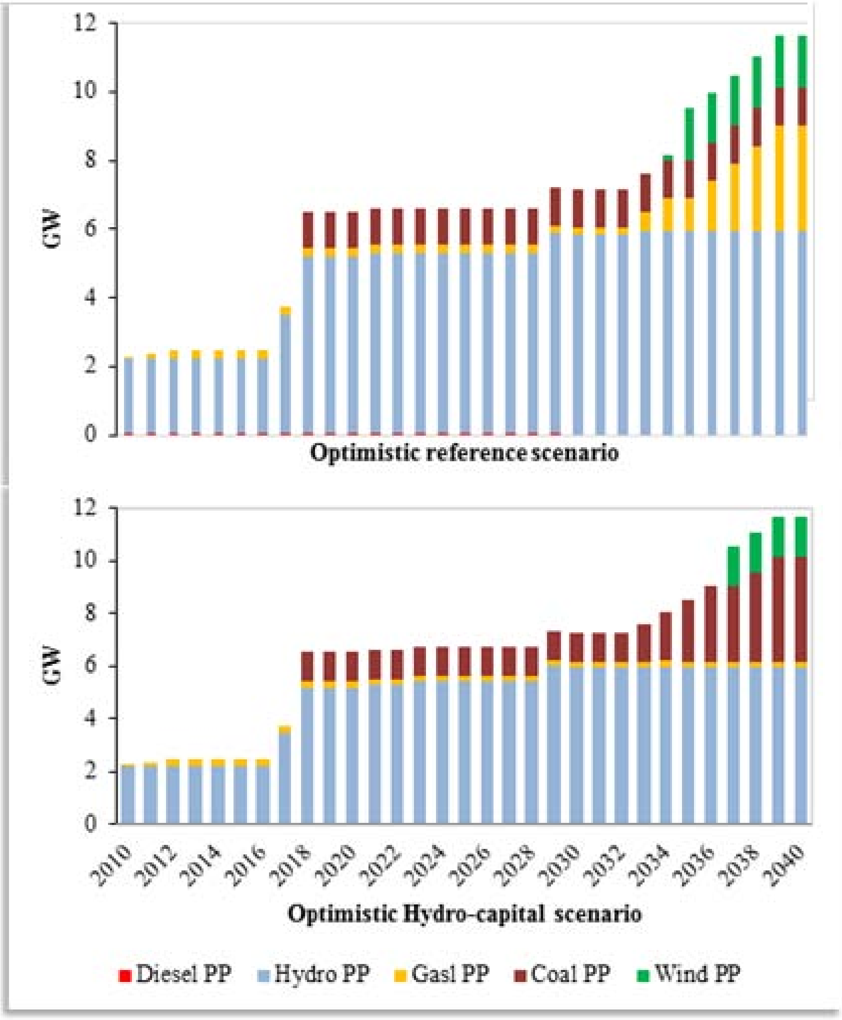

Figure 5.21 – Comparison of installed capacity in the Optimistic and hydro-capital scenarios

Regarding changes of other technologies, because investment costs of hydro power had increased, coal technology became competitive and thus its new capacity addition increased, while capacity addition of gas technology decreased. However, variation of total installed capacity was insignificant, since the Optimistic reference scenario showed 11.6 GW in 2040 and the Optimistic hydro-capital, presented 11.7 G in 2040 (figure 5.21).

Given the changes in capacity addition, total costs of expansion plan and the objective function were also affected and thus objective function increased from 59.96 billion USD to 66.67 billion USD (figure 5.22).

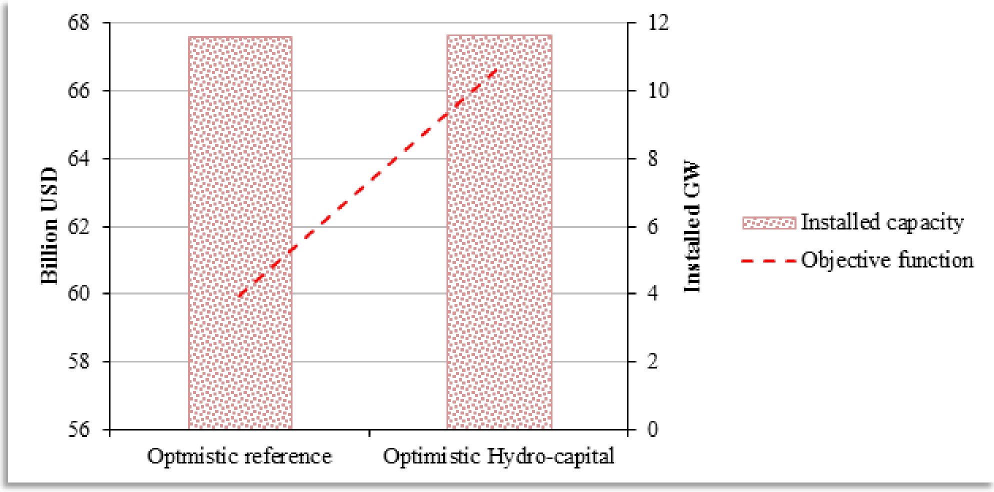

Figure 5.22 – Objective function and total installed capacity evaluation

On the other hand, changes in investment affected levelized cost of hydro power technology. As it is observed in figure 5.23, maintaining other technical parameter constant, the increase in investment costs is proportional to increased levelized cost. Sensitivity analyses were completed and the main outcomes of each scenario were compared with respect to energy security and reliability, CO_2 emissions and electricity prices.

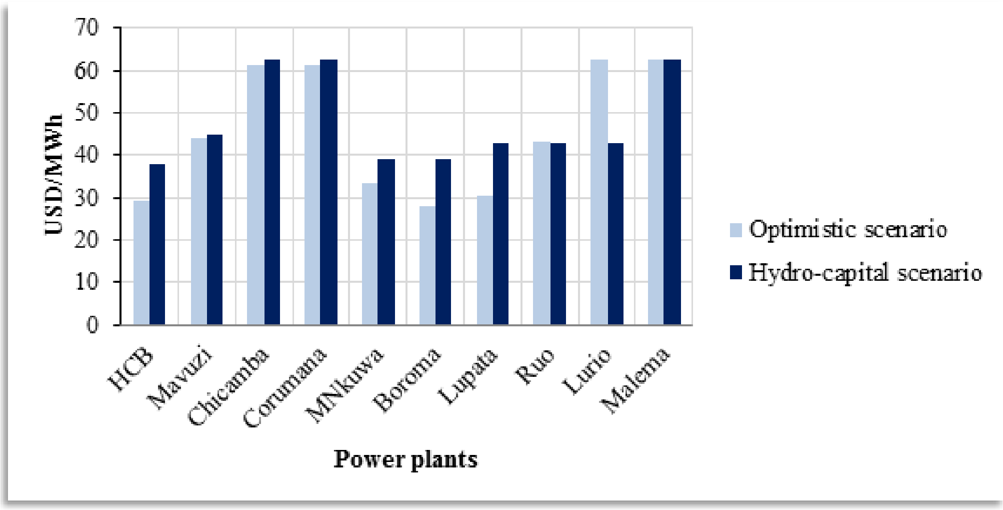

Figure 5.23 – Influence of investment in the levelized cost of hydro power

5.3.3. System diversity and reliability

According to Khatib (1997: 134), reliability of power supply system is usually defined as the global ability of the system to perform its role of balancing the demand at any time. This ability is often related with the system's security to respond to instabilities arising internally and thus, the existence of sufficient power plants within the system in order to satisfy the demand.

Apart from aspects related with quality and existence of satisfactory power plants, another indicator of power system reliability is the diversified technology mix within the system. Systems that rely on multiple sources of primary energy are more robust to shocks, constraints and crises affecting one or another form of supply (IRENA 2013: 42). A commonly used indicator of systems diversity is the Shannon-Weiner Index (SWI), defined as:

$$SWI = -\sum \rho_i \ln(\rho_i) \qquad (5.4)$$

Where:

ρ_i - is the share of installed capacity for resource i.

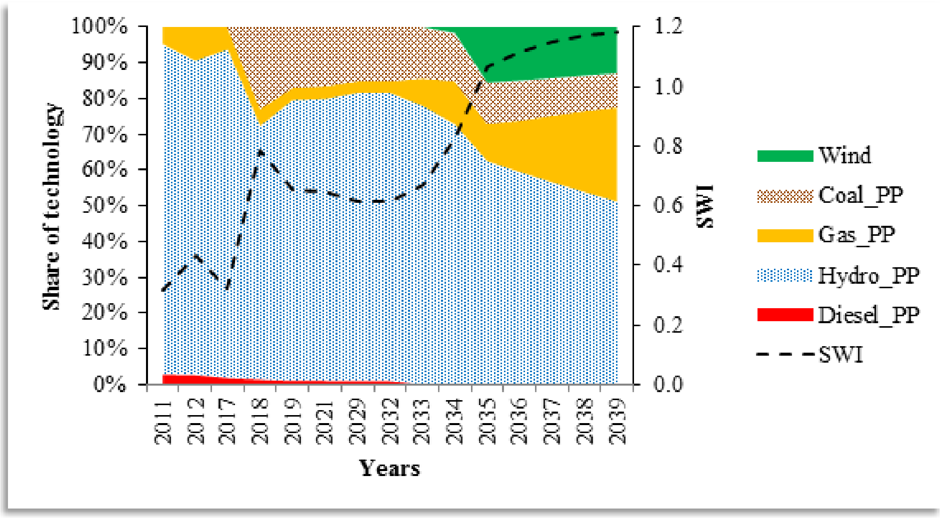

Figure 5.24 – Share of resource and SWI in the Optimistic reference scenario

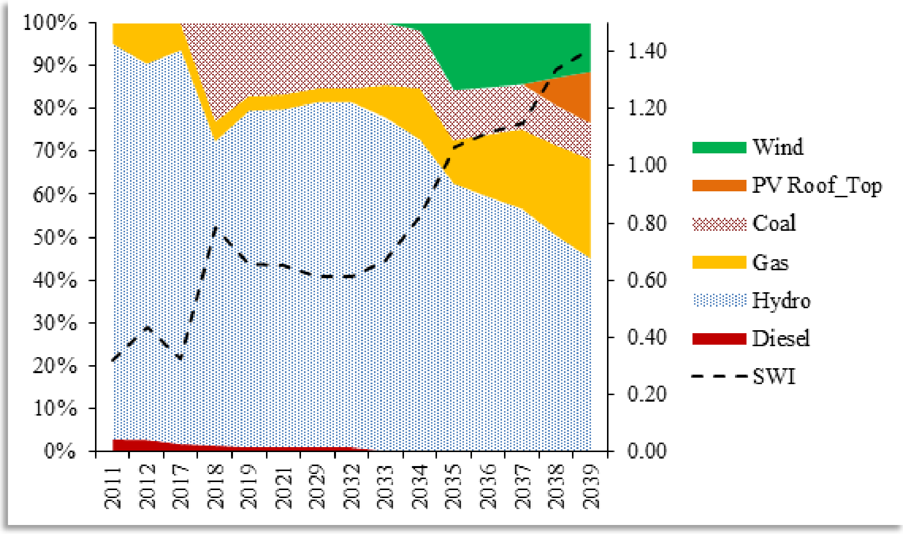

Figure 5.25 – Share of resource and SWI in the Optimistic PV roof-top scenario

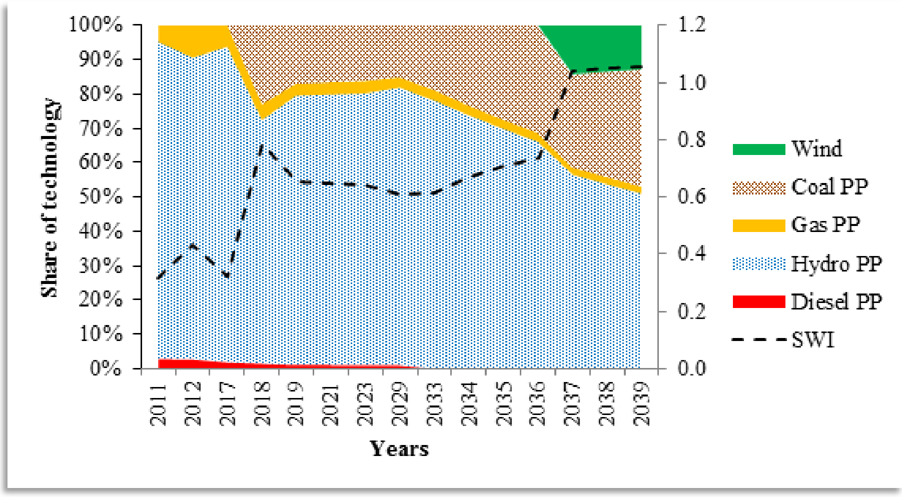

Figure 5.26 – Share of resource and SWI in the Optimistic Hydro-capital scenario

Comparing the SWI of the scenarios (figures 5.24, 5.25 and 5.26), it is noted that the Optimistic solar PV roof-top scenario, apart from containing solar and wind technologies, also comprises a diversified supply mix than other scenarios. Thereby, the higher the value of SWI, the more diverse and balanced the system is. In 2011 the system comprised 92.47% of hydropower technology and 7.6% of gas and diesel technologies, whereas in 2040, the system will comprise comprises 45% of hydropower, 31.6% of gas and coal technologies and 23.4% of renewable technology (solar and wind).

Because measuring security of energy supply is becoming an important topic on the studies of energy policy, the SWI can serve as a tool to assess long-term energy security strategies. Therefore, taking into consideration the country's poor diversity of supply mix in 2010, the more balanced share of technologies in the Optimistic PV roof-top supply scenario makes the energy system more robust, secure and reliable.

Regarding the concern with CO_2 emission, in the Optimistic hydro-capital scenario, a significant increase of new capacity from coal was noted. As is known, coal is the cheapest fossil fuel compared with oil and natural gas but is the largest contributor of CO_2 emission worldwide.

Using expression 5.5 computed by the IEA for calculation of CO_2 emission per kWh and ignoring the portion of CO_2 associated with the production of heat and own electricity use, CO_2 emission can be estimated. As is noted in figure 5.25, the hydro-capital scenario presents the highest amount of CO_2 emission compared with other scenarios, since renewable energy emits virtually nothing and gas technology emits almost 50% of coal's CO_2 emission estimated in 0.9 kg per kW of electricity generated.

$$CO_{2(kWh)} = \frac{CO_{2(Elect)} + CO_{2(CHP)} \cdot \%_{(Elect)} + OWN_{use(Elect)}}{EL_{Output(Plant)} + EL_{Output(CHP)}} \tag{5.5}$$

Where:

$CO_{2(kWh)}$ - is CO_2 emission per kWh generated;

$CO_{2(Elect)}$ - is CO_2 emission resulting from power generation only plants;

$CO_{2(CHP)}$ - is of CO_2 emission resulting from combined heat and power generation plants (CHP);

$\%_{(Elect)}$ - is the fraction of electricity generated from heat and power plants (CHP);

$OWN_{use(Elect)}$ - is CO_2 emission resulting from use of electricity in CHP;

$EL_{Output(Plant)}$ - represents power output from electricity only plants and;

$EL_{Output(CHP)}$ - represents electricity output from CHP.

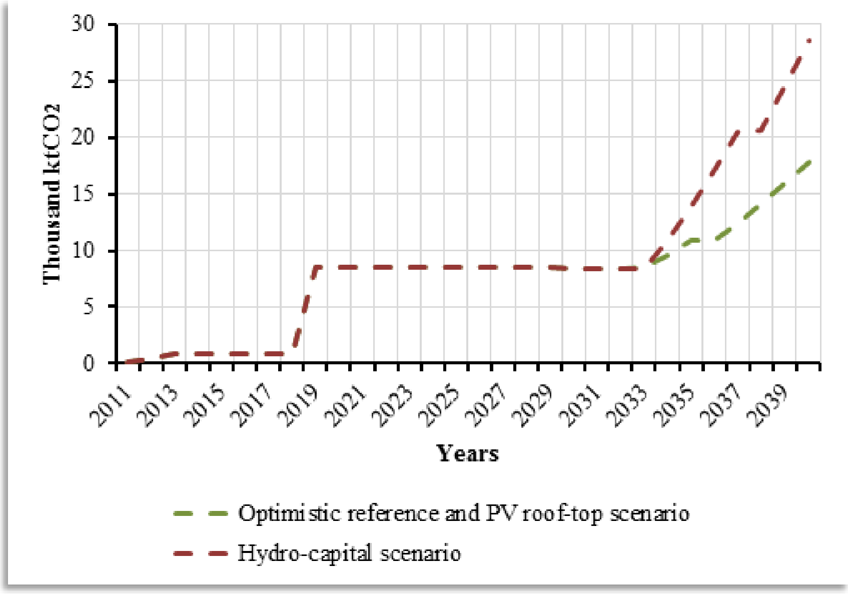

Figure 5.27 – Comparison of CO_2 emission from power generation

The IEA's 2012 CO_2 emission estimates resulting from fuel combustion states that in 2010, Mozambique's power sector has released virtually no CO_2, whereas South Africa's power sector has released 237.8 million tonnes of CO_2. Therefore, despite considerable addition of fossil fuel technology, the power sector of Mozambique will still remain one of which has low rates of CO_2 emission. However, the introduction of renewable energy in the power sector not only enables to mitigate CO_2 emission but also reduces investment costs as result of saving costs in fuel. On the other hand, investment costs of renewable energy technologies are expected to decrease in near future and thus, stimulating the emergence of power generation projects.

5.3.4. Evaluation of electricity price

How energy modelling team select the best alternative of power supply is not always merely a matter of just identifying the option with the lowest cost. Selection may be based on the relative merits of costs versus saving, the benefit versus cost. In an integrated resource planning (IRP) situation, the decision may also depend on the applicable philosophy about what constitute savings and who should benefit most from a public utility's investment in the system (Willis & Scott 2000: 144).

About what will be the price of electricity, an estimate was made taking into account annual costs based on investment costs, fixed and variable O&M costs and fuel cost. End-user electricity prices are determined by the underlying costs of supplying electricity, including the cost of generating electricity, transmitting and distributing it through the network, and selling it to the final customer. However, it is important to highlight that the price of electricity estimated in this study refers only to generation, not including costs of transmission and distribution, since it was not possible to find information regarding transmission and distribution network.

From the discount previously assumed, using interest during construction (IDC), related to interest accumulated during construction period, which usually equals capitalized interest and capital recover factor (CRF), the annual amortized capital of the investment cost was calculated as:

$$Amortized\ capital = \frac{\$}{kW} \cdot CRF \cdot IDC \tag{5.6}$$

Then, the annualized capital (million USD) representing annual expenditure in power generation for each power plant was calculated as:

$$\frac{(Amortized\ value + fix.O\,\&\,M) * MW + Var.O\,\&\,M * GWh}{1000} + \frac{fuel\ \cos ts}{1000000} \tag{5.7}$$

The annual electricity price was estimated as:

$$Electricit\,y\ \ price = \frac{Total\ \ annualized\ \ capital\ \ in\ the\ \ year}{Total\ \ power\ \ generation\ \ in\ the\ \ year} \tag{5.8}$$

Figure 5.28 illustrates the trajectory of annual electricity price related to power generation in the Optimistic reference scenario. As it is noted, an upward trend of electricity price will occur in the period of study. Electricity price rises significant reaching a peak of 0.074 USD/kWh in 2018 due to expenses in fuel costs (natural gas), since the first additional capacity of hydro power plant occurs by 2017. Taking into account these additional investments in transmission and distribution lines and other related to update of substation and transformers, electricity price at distribution points can double compared with the trajectory presented in figure 5.28. Note that the average electricity price within the period of study is about 0.051 USD/kWh.

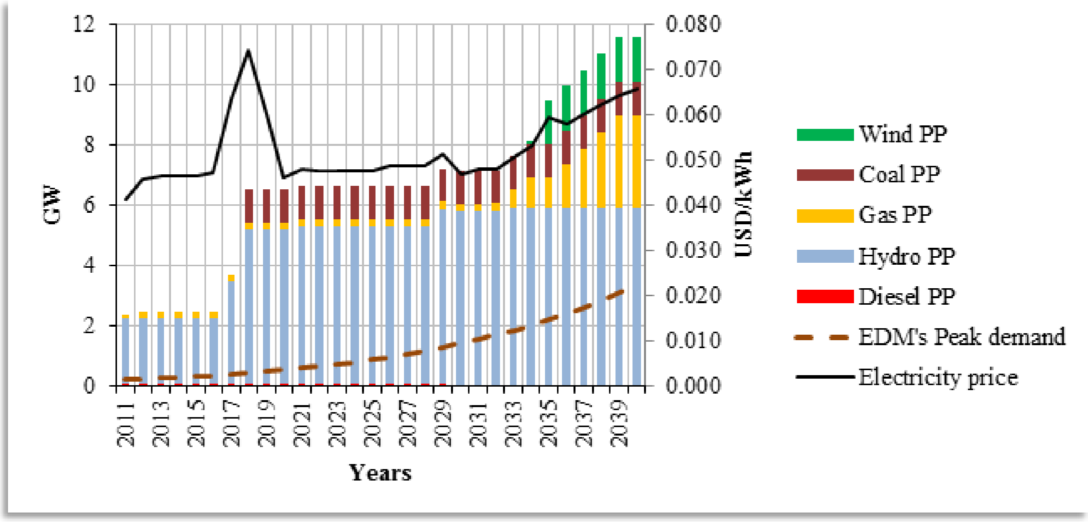

Figure 5.28 – Trajectory of annual electricity price in Optimistic PV roof-top scenario

5.4. Options regarding power system operation

Currently, Mozambique's energy system is composed of Hydropower, diesel and gas power plants. Hydropower represents the largest source of electricity generation, contributing with approximately 96% of the electricity generated. Because many of diesel power plants are old and will retire soon, the only viable option is to introduce new power plants to cover the peak demand. It is important to highlight that EDM´s diesel power plants are shut down practically all the time, due to costs of diesel on the one side and due to breakdown on the other side. Thereby, emerges the need of introducing new gas and coal power plants into the energy system.

5.4.1. Peaking plants

In order to decide what types of plants are required for base load, intermediate and peak load, there is a need of drawing levelized cost curves, taking into account the annualized capital of the power plant and the capacity factor. The base load is the load below which the demand never falls and is supplied 100% of the time. According to IAEA (1984:

177), typical capacity factor for base load range from 40-70%, for intermediate load from 20-40% and for peak load 0-20%.

Analysing the figure 5.29 it is noted that diesel power plants represent the first option for balancing peak load demand. However, in the absence of diesel units, gas technology should be the one used for peak load demand. Natural gas can be burn easily, enabling the power plant to be shut down and start-up quickly.

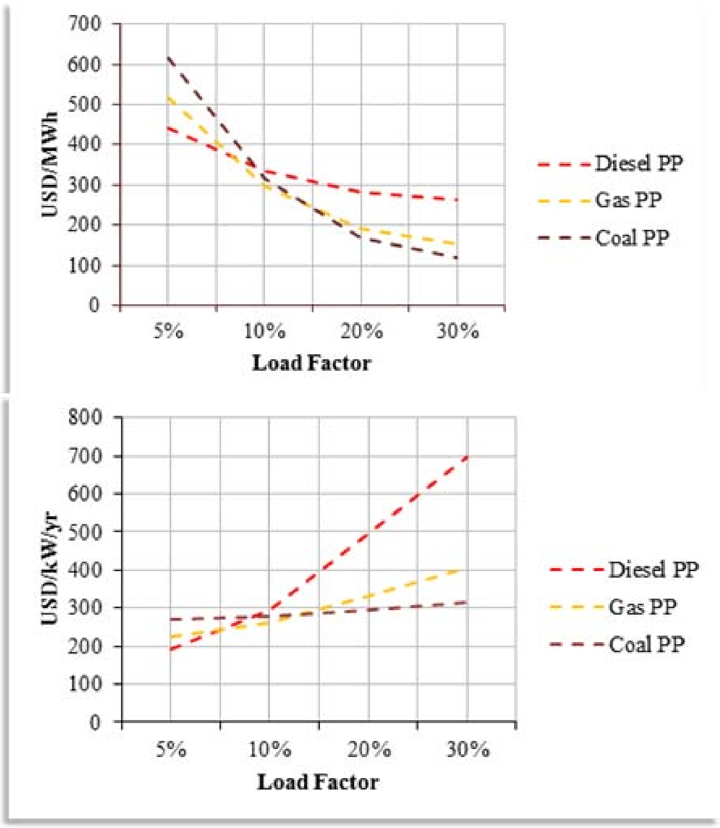

Figure 5.29 – Peak load power plants

Gas-fired power plants are built rapidly and, in most cases, expenditures are spread over two to three years. The O&M costs are significantly lower than those of coal-fired and the high fuel costs can be tolerated since the peak load plants are operated only occasionally.

5.4.2. Intermediate and base load plants

In Mozambique, coal power technology is not implemented yet, but the government approved the construction of Benga and Moatize coal power stations, which will produce 500 and 600 Megawatts of electricity respectively. Considering that coal is an important source of energy worldwide, particularly for power generation and taking into account that Mozambique possesses vast reserves of coal it is acceptable that the country should introduce this technology.

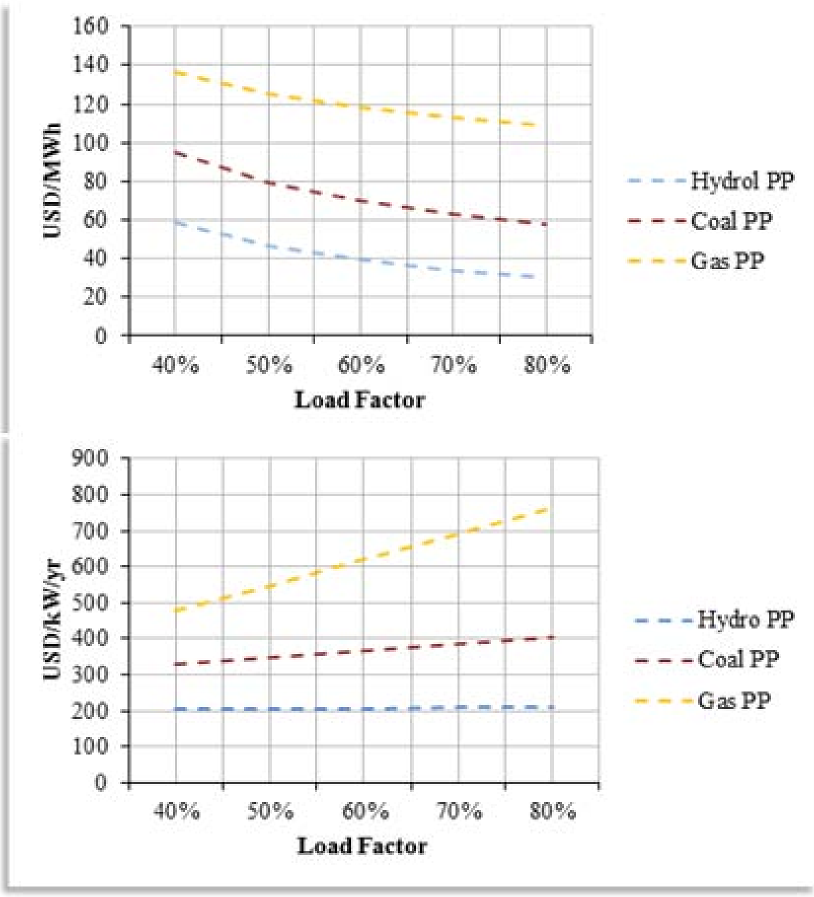

Figure 5.30 – Intermediate and base load power plants

Analysing figure 5.30 it can be observed that coal power plants are suitable for intermediate and base load demand. Hydropower plants are extremely efficient for balancing intermediate and base load demand. An exception can be considered regarding the operational characteristic of hydropower. Despite the low capital cost, hydropower can be run for peaking load purpose. However, in many cases it is impossible to run hydropower at rated load for most of the year, as the water required will exceed the total available. Given this, hydropower may be used for peak load only during those portions of the year when the load is highest (Weisman, 1985: 17).

The reason for this procedure is justified by the fact that its use in peak load could cause water shortage and thus, affecting its performance to cover base load demand, since it is known that hydropower is essential for that purpose. Therefore, even in the case of reservoir hydro plants could be used for peak-load provision, this option could lead to a high electricity generation costs due to the limited time with which the plants are operated.

As is observed in figure 5.31, due to shortage of water in dry year season, to operate hydropower becomes more expensive and therefore, hydropower begins to be not suitable for covering peak load. In that context, during dry year season, hydropower technology cannot be run at all the time and consequently there is also necessity to shut down the plant in order to save water.

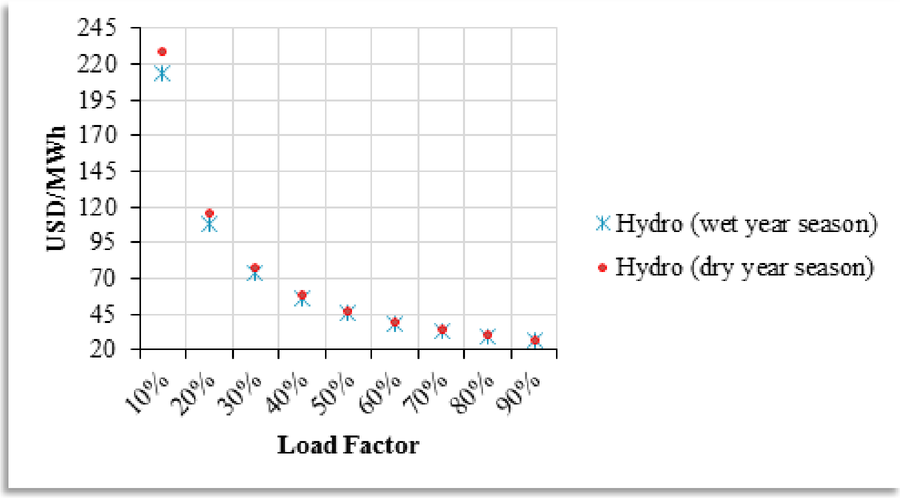

Figure 5.31 – Influence of capacity factor in levelized cost of hydropower

CHAPTER 6 – SUMMARY AND CONCLUSIONS

6.1. Sum up of the study

Currently, many studies are carried out worldwide in the topic related to energy issues, in view of deepening an understanding of this important matter or to producing new knowledge. When the study involves the collection of data, the researcher may find innumerous barriers in different steps of the study, because of lack of information. In the specific case of this study, reliable information related with power plant operation, for an individual unit or for the total number of units comprising the energy system of Mozambique was not easy to obtain.

It was noted that in Mozambique, companies still have a perception that the request for information related to their operation means to interfere in the business of the company, even in the case of public companies, which have an obligation of publishing activity reports. This unwillingness to release information becomes more pronounced when it is related to energy issues, that are considered very sensitive, since it involves matters of energy resources exploitation and use, such as environmental impacts, social role of the energy sector and the benefits gain by the companies in the business of power generation or resource exploitation.

On the other hand, in the few cases where the information is available, such information often appears incomplete, forcing the researcher to fill this gap with assumptions that may create discrepancy in the outcomes of the study. IAEA (1984: 88), states in its guidebook for expansion planning for electrical generation system that a major complexity facing the electric system planner is the uncertainty introduced in studies over a long time horizon. Investment costs, fixed and variable costs and other relevant information needed for modelling the energy system vary from source to source, increasingly complicating the task of modelling the system.

In that context, it is important to make some remarks, expressing what was perceived when using the optimization modelling tool MESSAGE. First of all, to highlight that MESSAGE is a powerful tool for modelling an energy system, since it helps the modeller to calculate several times the objective function expressed by a number of constraints.

MESSAGE has some limitations, mainly related to the probabilistic nature of unexpected outages in thermal plants, and availability of certain resources such as water for hydro, wind and the sun. In the version of the model used, other simplifications such as a relatively low resolution on the load shape, not ramp-rate constraints, and the lumpiness of some new investments have been ignored by using an LP solver.

These simplifications made in order to make the model solve faster and the other short-comings causes some differences between what is seen in the results and how plants operate in reality. These simplifications could be improved on as models become more sophisticated and more time becomes available to expand on the analysis. In that context, MESSAGE is a tool that helps to optimize the expansion plan and the results need to be assessed and brought near a real situation.

6.2. Relevant point views of the study

Although there have been referenced some limitations of the study, many issues related to planning, generation and power dispatch that the researcher was unaware of are now clearer, with more emphasis on the issues of planning and optimizing energy system.

According to Stoll (1989: 167), the electric utility industry planning process begins with the electricity load-demand forecast. The demand for electricity initiates actions by utilities to add or retire generation, transmission, or distribution capacity. Because of the long time required to licence and construct new utility equipment, decisions must be made 2-10 years in advance of the need for a new utility plant. The optimal mix of future capacity additions is dependent not only on the economic characteristic of the new generating unit alternatives but also on the existing composition of the generating units.

The operating cost of gas thermal plants is very high, though their capital cost is low. So, it has become economical as well as convenient to have gas thermal power plants, hydropower plants and other technologies in the same grid. Since the sources of energy are so diverse (coal, oil, gas, river water, marine tide, sun power, radioactive matter), the choice of one or other is made on economic, technical or geographic basis.

In the case of Mozambique, it was clearly noted that the government has taken in consideration economic, technical and geographic factors to approve new projects of power generation. For example, the Benga and Moatize coal power plants and the Temane gas power plant are located near coal and gas mining.

As there are few facilities to store electrical energy, the net production of a utility must clearly track its total load. In this study, LEAP was used to project electricity demand linked with variables of development such as GDP and population growth. Looking at the results related to the Optimistic scenario, Mozambique's population is expected to increase from 21.85 million people in 2010 to 49.0 million people in 2040.

As a result levels of electricity consumption are expected to rise from 10.24 TWh in 2010 to 80.12 TWh in 2040, with the industrial sector accounting for the largest percentage of demand (65.7 %), followed by the residential (30.4 %). The annual average consumption in the residential sector will increase from 1218 kWh per household in 2010 to 2496 kWh per households in 2040. In order to provide welfare to the citizens, Mozambique's government will need to increase access to electricity from 16% in 2010 to 75 % in 2040.

This increase in access to electricity requires the addition of new power infra-structures, mainly power plants. On the other hand, the diversification of power sources will be fundamental for the reliability of the power system. In order to balance this electricity demand, MESSAGE was used to compute different supply alternatives, presenting the annual power output of existing capacities and new capacity addition.

As a result, it was observed that in the Optimistic scenario, electricity generation increases from 12.4 TWh in 2010 to 69.7 TWh in 2040. In the decade 2020 – 2030, export of electricity will exceed the actual electricity import necessary to cover the consumption of MOZAL estimated in 8.3 TWh. Both renewable and non-renewable energy sources contribute for balancing the demand. Even with the addition of considerable capacity of coal and gas power plant technologies, hydropower continues to be dominant technology in all scenarios. In the Optimistic scenario, this technology, parallel with other renewable technologies account for 64 % of total installed capacity.

Considering the outcomes presented by other studies (SAPP master plan and SAPP IRENA etc.), the findings of this study, regarding the projection of electricity demand and supply could represent a new source for future studies. In fact, significant differences in projections were noted comparing this study with those previous studies. For example, in the SAPP IRENA study, from 2010 to 2030, new capacity addition and power generation totalized 2982 MW and 8840 GWh respectively, while in this study, for the same period, total capacity addition and power generation are estimated in 4972 MW and 42.8 TWh respectively.

However, taking into account simplifications made in the model, possible extension of this study could present more refined outcomes, mainly in aspects related to:

- ✓ modelling of hydro with no seasonal fluctuations;
- ✓ country modelled as a single node (north and south combined);
- ✓ further assessment of wind;
- ✓ more refined analysis of grid costs for better analysis of distributed generation and;
- ✓ more sensitivity analysis around the price of gas, and coal.

6.3. Conclusions

This study was undertaken to address certain concerns related to economic and sustainable development of the power sector of Mozambique in order to answer not only the research questions but also to fulfill with the objectives set for the study.

Starting by looking at the research questions, the first question asks to what extent the usage of coal and gas in electricity generation contributes to developing the power sector and the economy of the country. As it was observed in all power supply alternatives (supply scenarios), Mozambique's power sector began with an installed capacity of about 2251 MW and the usage of coal and gas incremented value, increasing the availability of electricity up to 11.6 GW as presented in figure 5.16.

Thereby, it is clear that the power sector has developed and thus, in the absence of these technologies, the power sector would need to import more electricity, continuing to be dependent and facing shortage of electricity.

In all scenarios it was noted that the introduction of coal and gas technologies, not only enables the balance between supply and demand of electricity, but also contributes to increased export of electricity in early years, which could be an important source of revenues for Mozambique. Comprising a diversified mix of technologies, the energy system becomes more robust, secure and reliable. In terms of contribution to economy, the new capacities represent additional revenues for the power sector and increment of employment rates in the country.

Regarding the question to what extent does the usage of these resources meet all dimensions of sustainability for the country, first of all it is important to highlight the social role of energy, strictly linked with social and economic dimension of sustainability. Access to modern energy sources such as electricity can boost the wellness of the communities in various aspects of economic and social scope (business, education, health and habitation). Unfortunately, it is not possible to comprehensively evaluate the socio-economic impact of the scenarios modelled, as this would require the use of other models not considered in this thesis (e.g. CGE models). However, the scenarios do focus on access and use of electricity by households, and access to modern energy sources.

In relation to the environmental dimension of sustainability, the profound technological advancement in the power generation from coal and gas may allow to overcome the challenge of polluting the environment. Thereby, operating the power plants when necessary, for example, gas for peak load demand and coal for intermediate load demand may increase the efficiency and moderate the operation of the power plant. On the other hand the right combination of policies and technologies is proving that the links between economic growth, energy demand and energy-related CO_2 emissions can be weakened (IEA, 2013: 23)

Assessing the main objective of the study, related to demand forecast and the optimization of power dispatch, it is important to underline that the use of modelling approach helps to simulate a real situation. Based on the collected data related to electricity generated and demanded, access to electricity and variables of development, modelling approaches were used to project future electricity demand and find alternatives of balancing the demand through evaluation of supply alternatives.

Finally, as recommendations, the following policies are seen as relevant for Mozambique's power sector:

- ✓ power sector planning and management capabilities improvement in order to cope with the increasing requirement and complexities of the sector;
- ✓ to secure a cost-effective supply by choosing an appropriate mix of technologies to meet future demand;
- ✓ to diversify supplies in order to reduce the dependence on any particular fuel or sources of supply;
- ✓ as power generation costs have been rising, there is a need of setting mechanisms to improve energy efficiency in order to avoid waste of energy;
- ✓ increase of power production from renewable source creating incentive for the expansion of solar PV roof-.top in the residential sector and;
- ✓ expansion of gas power plants to the northern region of the country.

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APPENDICES

Appendix A – *Demographic and development data*

Table A1 – Mozambique's population and development index (Source: INE, EDM, BM)

Year	2005	2006	2007	2008	2009	2010	2011
Population (million)	*19.42*	*19.89*	*20.53*	*20.85*	*21.35*	*21.85*	*22.42*
Households (million)	*3.884*	*3.978*	*4.106*	*4.17*	*4.27*	*4.37*	*4.484*
Electrified households (%)	*7.78*	*9.4*	*11.3*	*13.41*	*15.94*	*18.09*	*20.85*
GDP (million USD)	*6.823,0*	*7.738,0*	*8.053,6*	*9.390,6*	*10.773,8*	*10.784,5*	*12.338.2*
GDP per capita (USD)	*351.33*	*389.04*	*392.28*	*450.38*	*504.63*	*493.08*	*550.32*
kWh per capita	*85*	*89*	*96*	*106*	*118*	*130*	*143*
Access elect. (%)	*7*	*8*	*10*	*12*	*14*	*16*	*18*
Urban population (%)	*34.5*	*35.2*	*36*	*36.7*	*37.5*	*38.2*	*39*
Rural population (%)	*65.5*	*64.8*	*64*	*63.3*	*62.5*	*61.8*	*61*

Appendix B - *Existing power plants output and new planned capacity addition*

Table B1 – Annual power output of existing power plants in GWh (Source: HCB, EDM, SASOL)

Year	2005	2006	2007	2008	2009	2010
Hydro HCB	*13264.0*	*14491.0*	*15847.0*	*14774.0*	*16574.15*	*16290.0*
Hydro EDM	*158.0*	*218.0*	*216.0*	*341.0*	*375.0*	*350.0*
Gas EDM	-	-	*3.73*	*4.6*	*10.9*	*19.41*
Diesel EDM	-	*5.5*	*3.6*	*3.3*	*3.9*	*7.7*
TOTAL (GWh)	***13422***	***14714.5***	***16070.33***	***15122.9***	***16963.95***	***16667.11***

Table B2 – New planed capacity addition in MW (Source: EDM, SAPP)

Power Plant	Capacity	First Year	Effic.	FOR	POR	PF	Op.T
Hydro HCB	*1245.0*	*2018*	-	*2.0%*	*5.0%*	*98.0%*	*67.3%*
Hydro M. Nkuwa	*1500.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*65.3%*
Hydro Lupata	*600.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*59.2%*
Hydro Boroma	*200.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*65.3%*
Hydro Ruo	*100.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*59.2%*
Hydro Malema	*60.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*21.4%*
Hydro Lurio	*120.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*21.4%*
Hydro Massingir	*27.0*	*2019*	-	*2.0%*	*5.0%*	*98.0%*	*21.4%*
Gas Aggreko	*230.0*	*2011*	*53.0%-*	*7.0%*	*7.0%*	*93.0%*	*93.0%*
Gas Moamba	*700.0*	*2016*	*53.0%*	*7.0%*	*7.0%*	*93.0%*	*93.0%*
Gas Kuvaninga	*60.0*	*2016*	*48.0%*	*7.0%*	*7.0%*	*93.0%*	*93.0%*
Gas Maputo	*50.0*	*2016*	*48.0%*	*7.0%*	*7.0%*	*93.0%*	*93.0%*
Gas Temane	*750.0*	*2016*	*48.0%*	*7.0%*	*7.0%*	*98.0%*	*93.0%*
Coal Benga	*500.0*	*2018*	*37.0%*	*2.0%*	*7.0%*	*93.0%*	*93.0%*
Coal Moatize	*600.0*	*2018*	*37.0%*	*2.0%*	*7.0%*	*93.0%*	*93.0%*
Solar_PV	-	*2015*	-	*2.0%*	*5.0%*	*98.0%*	*100.0%*
Wind	*1500.0*	*2015*	-	*2.0%*	*5.0%*	*98.0%*	*100.0%*
Coal Generic	-	*2017*	*37.0%*	*2.0%*	*7.0%*	*93.0%*	*93.0%*
Gas Generic	-	*2017*	*48.0%*	*2.0%*	*7.0%*	*93.0%*	*93.0%*

Appendix C – *EDM's available electricity, number of customers and consumption*

Table C1- EDM's available electricity for customers and internal use (Source: EDM)

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Produced	*173*	*2130*	*2381*	*2653*	*2775*	*368*
Purchased	*19*	*224*	*224*	*352*	*386*	*3118*
Imported	*1905*	*27*	*17*	*28*	*32*	*68*
TOTAL (*GWh*)	***2097***	***2381***	***2622***	***3032***	***3193***	***3553***
CONSUMED (*GWh*)	*1652*	*1873*	*2029*	*2404*	*2449*	*2777*
LOSSES (*GWh*)	*445*	*508*	*523*	*628*	*744*	*776*

Table C2- Total customers of EDM (Source: EDM)

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Residential	*302215*	*373795*	*464197*	*559433*	*680583*	*790858*
Commercial	*33809*	*38790*	*43275*	*51620*	*51460*	*62855*
Industrial	*2920*	*3058*	*3353*	*3648*	*4005*	*4358*
Agriculture	*7*	*24*	*22*	*30*	*35*	*37*
TOTAL (*Customers***)**	***338951***	***415667***	***510847***	***614731***	***736083***	***858108***

Table C3 – EDM's billed electricity (GWh) in Mozambique and SADC region (Source: EDM)

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Residential	*481.0*	*517.0*	*581.0*	*648.0*	*751.0*	*891.0*
Commercial	*160.0*	*183.0*	*195.0*	*198.0*	*222.0*	*219.0*
Industrial	*614.0*	*624.0*	*670.0*	*784.0*	*826.0*	*933.0*
Agriculture	*0.07*	*0.07*	*0.1*	*0.1*	*0.28*	*0.36*
Special	-	-	*15.0*	*60.0*	*88.0*	*96.0*
SADC	*362.0*	*498.0*	*523.0*	*670.0*	*514.0*	*580.0*
TOTAL (*GWh***)**	***1617.1***	***1822.1***	***1984.1***	***2360.1***	***2401.3***	***2719.4***

Appendix D – *Demand results*

Table D1 – Mozambique's projected population (million people) by scenario

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Borderline	*21.85*	*24.72*	*27.97*	*31.49*	*34.77*	*38.39*	*42.38*
Optimistic	*21.85*	*25.33*	*29.36*	*33.88*	*38.33*	*43.36*	*49.06*

Table D2 – Mozambique's projected GDP (billion U.S Dollar) by scenario

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Borderline	*9.99*	*12.54*	*15.7*	*19.45*	*23.72*	*28.41*	*33.74*
Optimistic	*9.99*	*13.28*	*17.57*	*22.93*	*29.36*	*36.87*	*45.95*

Table D3 – Mozambique's projected GDP (billion U.S Dollar) per economic sector in the Optimistic scenario

Year	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Agriculture	*2.687*	*3.561*	*4.700*	*6.118*	*7.814*	*9.791*	*12.174*
Commercial	*4.066*	*5.297*	*6.874*	*8.806*	*11.082*	*13.697*	*16.808*
Manufacturing	*1.648*	*2.178*	*2.867*	*3.721*	*4.742*	*5.927*	*7.354*
Electricity	*0.519*	*0.690*	*0.914*	*1.192*	*1.527*	*1.917*	*2.390*
Steel	*1.648*	*2.178*	*2.867*	*3.721*	*4.742*	*5.927*	*7.354*
Mining	*0.459*	*0.611*	*0.808*	*1.055*	*1.351*	*1.696*	*2.114*
Total (*Billion USD*)	***11.030***	***14.520***	***19.030***	***24.610***	***31.260***	***38.960***	***48.190***

Table D4 – Mozambique's projected electricity consumption (thousand GWh) by scenario

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Borderline	*10.24*	*14.24*	*19.70*	*26.98*	*34.49*	*43.39*	*54.30*
Optimistic	*10.24*	*15.16*	*22.46*	*32.9*	*44.67*	*59.82*	*80.12*

Table D5 – Mozambique's projected electricity consumption (thousand GWh) by economic sector in the Optimistic scenario

Year	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Agriculture	*0.0003*	*0.0005*	*0.0009*	*0.0015*	*0.0025*	*0.0039*	*0.0061*
Commercial	*0.220*	*0.361*	*0.590*	*0.940*	*1.449*	*2.158*	*3.172*
Manufacturing	*0.920*	*1.610*	*2.790*	*4.710*	*7.640*	*11.940*	*18.380*
Electricity	*0.050*	*0.080*	*0.140*	*0.220*	*0.350*	*0.520*	*0.770*
Steel	*7.930*	*10.090*	*12.790*	*16.030*	*19.770*	*23.980*	*28.900*
Mining	*0.220*	*0.380*	*0.670*	*1.140*	*1.870*	*2.940*	*4.570*
Total	***9.3398***	***12.5217***	***16.9807***	***23.0415***	***31.0814***	***41.5423***	***55.7985***

Table D6 – Mozambique's projected households (million households) by scenario

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Borderline	*5.46*	*6.18*	*6.99*	*7.87*	*8.69*	*9.60*	*10.60*
Optimistic	*5.46*	*6.33*	*7.34*	*8.47*	*9.58*	*10.84*	*12.27*

Table D7 – Mozambique's projected electrified households (million households) by scenario

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Borderline	*0.874*	*1.854*	*3.147*	*4.724*	*5.505*	*6.398*	*7.417*
Optimistic	*0.874*	*1.990*	*3.539*	*5.505*	*6.548*	*7.769*	*9.199*

Table D8 – Mozambique's projected share of connections (%) in the residential sector

Type of households	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Low consumption	*64.6*	*59.7*	*56.8*	*53.9*	*51*	*47.8*	*45*	*42.3*
High consumption	*35.4*	*40.3*	*43.2*	*46.1*	*49*	*52.2*	*55*	*57.7*

Table D9 – Average consumption (kWh) per household in the residential sector (Optimistic scenario)

Consumption (kWh)	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Low consumption	*746.5*	*855.9*	*977.1*	*1105*	*1251*	*1388.5*	*1529.4*
High consumption	*1690.0*	*1938.0*	*2212.0*	*2502.0*	*2832.2*	*3143.5*	*3462.3*

Table D10 – Mozambique's residential sector electricity consumption (thousand GWh) in the Optimistic scenario

Consumption	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
High consumption	*0.54*	*1.66*	*3.61*	*6.76*	*9.67*	*13.42*	*18.37*
Low consumption	*0.36*	*0.97*	*1.86*	*3.10*	*3.92*	*4.86*	*5.95*
Total	***0.90***	***2.63***	***5.47***	***9.86***	***13.59***	***18.28***	***24.32***

Table D11 – Mozambique's residential electricity demand (thousand GWh) by scenario

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Borderline	*0.90*	*2.36*	*4.51*	*7.59*	*9.95*	*12.74*	*16.12*
Optimistic	*0.90*	*2.63*	*5.47*	*9.86*	*13.59*	*18.28*	*24.33*

Appendix E – *Supply results*

Table E1 – New capacity addition in MW representing the Borderline scenario

Year	Hydro PP	Gas PP	Coal PP	Solar PV	Wind	Total
2011	-	*106.9*	-	-	-	***106.9***
2012	-	*120.1*	-	-	-	***120.0***
2017	*1245.0*	-	-	-	-	***1245.0***
2018	-	-	*1100.0*	-	-	***1100.0***
2019	*1700.0*	-	-	-	-	***1700.0***
2021	*100.0*	-	-	-	-	***100.0***
2029	*600.0*	-	-	-	-	***600.0***
2034	-	*4.6*	-	-	-	***4.6***
2039	-	-	-	-	*185.0*	***185.0***

Table E2 – New capacity addition representing the Optimistic reference scenario

Year	Hydro PP	Gas PP	Coal PP	Solar PV	Wind	Total
2011	-	*106.9*	-	-	-	***106.9***
2012	-	*120.1*	-	-	-	***120.1***
2017	*1245.0*	-	-	-	-	***1245.0***
2018	-	-	*1100.0*	-	-	***1100.0***
2019	*1700.0*	-	-	-	-	***1700.0***
2021	*100.0*	-	-	-	-	***100.0***
2029	*600.0*	-	-	-	-	***600.0***
2032	*6.4*	-	-	-	-	***4.6***
2033	*113.6*	*346.5*	-	-	-	***460.1***
2034	-	*403.5*	-	-	*135.6*	***539.1***
2035	-		-	-	*1349.2*	***1349.2***
2036	-	*468.7*	-	-	*15.2*	***483.9***
2037	-	*505.3*	-	-	-	***505.3***
2038	-	*539.4*	-	-	-	***539.4***
2039	-	*575.9*	-	-	-	***575.9***

Table E3 – New capacity addition representing the Optimistic PV Roof-top scenario

Year	Hydro PP	Gas PP	Coal PP	Solar PV	Wind	Total
2011	-	*106.9*	-	-	-	***106.9***
2012	-	*120.1*	-	-	-	***120.1***
2017	*1245.0*	-	-	-	-	***1245.0***
2018	-	-	*1100.0*	-	-	***1100.0***
2019	*1700.0*	-	-	-	-	***1700.0***
2021	*100.0*	-	-	-	-	***100.0***
2029	*600.0*	-	-	-	-	***600.0***
2032	*6.4*	-	-	-	-	***4.6***
2033	*113.6*	*346.5*	-	-	-	***460.1***
2034	-	*403.5*	-	-	*135.6*	***539.1***
2035	-		-	-	*1349.2*	***1349.2***
2036	-	*468.7*	-	-	*15.2*	***483.9***
2037	-	*505.3*	-	-	-	***505.3***
2038	-	*539.4*	-	*771.9*	-	***1311.3***
2039	-	*575.9*	-	*816.3*	-	***1392.2***

Table E4 – New capacity addition representing the Optimistic hydro-capital scenario

Year	Hydro PP	Gas PP	Coal PP	Solar PV	Wind	Total
2011	-	*106.9*	-	-	-	***106.9***
2012	-	*120.1*	-	-	-	***120.1***
2017	*1245.0*	-	-	-	-	***1245.0***
2018	-	-	*1100.0*	-	-	***1100.0***
2019	*1700.0*	-	-	-	-	***1700.0***
2021	*100.0*	-	-	-	-	***100.0***
2023	*118.9*	-	-	-	-	***118.9***
2029	*600.0*	-	-	-	-	***600.0***
2033	*1.1*	-	*339.3*	-	-	***340.4***
2034	-	*4.6*	*436.5*	-	-	***441.1***
2035	-	-	*458.1*	-	-	***458.1***
2036	-	-	*488.6*	-	-	***488.6***
2037	-	-	*11.9*	-	*1500.0*	***1511.9***
2038	-	-	*556.4*	-	-	***556.43***
2039	-	-	*594.0*	-	-	***594.0***

Table E5 – Annual installed capacity (MW) by technology in the Borderline scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar	Wind	Total
2011	*65.0*	*2179.0*	*113.9*	*0.0*	*0.0*	*0.0*	*2357.9*
2012	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2013	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2014	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2015	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2016	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2017	*65.0*	*3424.0*	*234.0*	*0.0*	*0.0*	*0.0*	*3723.0*
2018	*65.0*	*3424.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*4823.0*
2019	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2020	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2021	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2022	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2023	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2024	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2025	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2026	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2027	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2028	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2029	*65.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*0.0*	*7227.6*
2030	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*0.0*	*7162.6*
2031	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*0.0*	*7162.6*
2032	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*0.0*	*7162.6*
2033	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*0.0*	*7162.6*
2034	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*
2035	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*
2036	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*
2037	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*
2038	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*
2039	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*
2040	*0.0*	*5824.0*	*238.6*	*1100.0*	*0.0*	*185.0*	*7347.6*

Table E6 – Annual installed capacity (MW) by technology in the Optimistic reference scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar	Wind	Total
2011	*65.0*	*2179.0*	*113.9*	*0.0*	*0.0*	*0.0*	*2357.9*
2012	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2013	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2014	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2015	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2016	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2017	*65.0*	*3424.0*	*234.0*	*0.0*	*0.0*	*0.0*	*3723.0*
2018	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2019	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2020	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2021	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2022	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2023	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2024	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2025	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2026	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2027	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2028	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2029	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2030	*0.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7158.0*
2031	*0.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7158.0*
2032	*0.0*	*5830.4*	*234.0*	*1100.0*	*0.0*	*0.0*	*7164.4*
2033	*0.0*	*5944.0*	*580.5*	*1100.0*	*0.0*	*0.0*	*7624.5*
2034	*0.0*	*5944.0*	*984.0*	*1100.0*	*0.0*	*135.6*	*8163.6*
2035	*0.0*	*5944.0*	*977.0*	*1100.0*	*0.0*	*1484.8*	*9505.8*
2036	*0.0*	*5944.0*	*1445.7*	*1100.0*	*0.0*	*1500.0*	*9989.7*
2037	*0.0*	*5944.0*	*1951.0*	*1100.0*	*0.0*	*1500.0*	*10495.0*
2038	*0.0*	*5944.0*	*2490.4*	*1100.0*	*0.0*	*1500.0*	*11034.4*
2039	*0.0*	*5944.0*	*3066.3*	*1100.0*	*0.0*	*1500.0*	*11610.3*
2040	*0.0*	*5944.0*	*3066.3*	*1100.0*	*0.0*	*1500.0*	*11610.3*

Table E7 – Annual installed capacity (MW) by technology in the Optimistic PV Roof-top scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar PV	Wind	Total
2011	*65.0*	*2179.0*	*113.9*	*0.0*	*0.0*	*0.0*	*2357.9*
2012	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2013	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2014	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2015	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2016	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2017	*65.0*	*3424.0*	*234.0*	*0.0*	*0.0*	*0.0*	*3723.0*
2018	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2019	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2020	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2021	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2022	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2023	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2024	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2025	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2026	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2027	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2028	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2029	*65.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7223.0*
2030	*0.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7158.0*
2031	*0.0*	*5824.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*7158.0*
2032	*0.0*	*5830.4*	*234.0*	*1100.0*	*0.0*	*0.0*	*7164.4*
2033	*0.0*	*5944.0*	*580.5*	*1100.0*	*0.0*	*0.0*	*7624.5*
2034	*0.0*	*5944.0*	*984.0*	*1100.0*	*0.0*	*135.6*	*8163.6*
2035	*0.0*	*5944.0*	*977.0*	*1100.0*	*0.0*	*1484.8*	*9505.8*
2036	*0.0*	*5944.0*	*1445.7*	*1100.0*	*0.0*	*1500.0*	*9989.7*
2037	*0.0*	*5944.0*	*1951.0*	*1100.0*	*0.0*	*1500.0*	*10495.0*
2038	*0.0*	*5944.0*	*2490.4*	*1100.0*	*771.9*	*1500.0*	*11806.3*
2039	*0.0*	*5944.0*	*3066.3*	*1100.0*	*1588.2*	*1500.0*	*13198.5*
2040	*0.0*	*5944.0*	*3066.3*	*1100.0*	*1588.2*	*1500.0*	*13198.5*

Table E8 – Annual installed capacity (MW) by technology in the Hydro-capital scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar	Wind	Total
2011	*65.0*	*2179.0*	*113.9*	*0.0*	*0.0*	*0.0*	*2357.9*
2012	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2013	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2014	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2015	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2016	*65.0*	*2179.0*	*234.0*	*0.0*	*0.0*	*0.0*	*2478.0*
2017	*65.0*	*3424.0*	*234.0*	*0.0*	*0.0*	*0.0*	*3723.0*
2018	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2019	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2020	*65.0*	*5124.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6523.0*
2021	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2022	*65.0*	*5224.0*	*234.0*	*1100.0*	*0.0*	*0.0*	*6623.0*
2023	*65.0*	*5342.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*6741.9*
2024	*65.0*	*5342.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*6741.9*
2025	*65.0*	*5342.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*6741.9*
2026	*65.0*	*5342.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*6741.9*
2027	*65.0*	*5342.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*6741.9*
2028	*65.0*	*5342.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*6741.9*
2029	*65.0*	*5942.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*7341.9*
2030	*0.0*	*5942.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*7276.9*
2031	*0.0*	*5942.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*7276.9*
2032	*0.0*	*5942.9*	*234.0*	*1100.0*	*0.0*	*0.0*	*7276.9*
2033	*0.0*	*5944.0*	*234.0*	*1439.2*	*0.0*	*0.0*	*7617.2*
2034	*0.0*	*5944.0*	*238.6*	*1875.7*	*0.0*	*0.0*	*8058.3*
2035	*0.0*	*5944.0*	*231.6*	*2333.8*	*0.0*	*0.0*	*8509.4*
2036	*0.0*	*5944.0*	*231.6*	*2822.4*	*0.0*	*0.0*	*8998.0*
2037	*0.0*	*5944.0*	*231.6*	*2834.3*	*0.0*	*1500.0*	*10509.9*
2038	*0.0*	*5944.0*	*231.6*	*3390.7*	*0.0*	*1500.0*	*11066.3*
2039	*0.0*	*5944.0*	*231.6*	*3984.7*	*0.0*	*1500.0*	*11660.3*
2040	*0.0*	*5944.0*	*231.6*	*3984.7*	*0.0*	*1500.0*	*11660.3*

Table E9 – Annual power output (GWh) by technology in the Borderline scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar PV	Wind
2011	*122.8*	*12192.0*	*53.1*	*0.0*	*0.0*	*0.0*
2012	*122.8*	*12192.0*	*907.5*	*0.0*	*0.0*	*0.0*
2013	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2014	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2015	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2016	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2017	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2018	*122.8*	*19362.7*	*1868.0*	*0.0*	*0.0*	*0.0*
2019	*122.8*	*19362.7*	*1868.0*	*8525.0*	*0.0*	*0.0*
2020	*122.8*	*28861.9*	*1868.0*	*8525.0*	*0.0*	*0.0*
2021	*122.8*	*28861.9*	*1868.0*	*8525.0*	*0.0*	*0.0*
2022	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2023	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2024	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2025	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2026	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2027	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2028	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2029	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2030	*122.8*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2031	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2032	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2033	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2034	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2035	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2036	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2037	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2038	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2039	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2040	*0.0*	*33020.9*	*1850.0*	*8525.0*	*0.0*	*486.8*

Table E10 – Annual power output (GWh) by technology in the Optimistic reference scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar PV	Wind
2011	*122.8*	*12191.9*	*53.1*	*0.0*	*0.0*	*0.0*
2012	*122.8*	*12191.9*	*907.5*	*0.0*	*0.0*	*0.0*
2013	*122.8*	*12191.9*	*1868.0*	*0.0*	*0.0*	*0.0*
2014	*122.8*	*12191.9*	*1868.0*	*0.0*	*0.0*	*0.0*
2015	*122.8*	*12191.9*	*1868.0*	*0.0*	*0.0*	*0.0*
2016	*122.8*	*12191.9*	*1868.0*	*0.0*	*0.0*	*0.0*
2017	*122.8*	*12191.9*	*1868.0*	*0.0*	*0.0*	*0.0*
2018	*122.8*	*19362.7*	*1868.0*	*0.0*	*0.0*	*0.0*
2019	*122.8*	*19362.7*	*1868.0*	*8525.0*	*0.0*	*0.0*
2020	*122.8*	*28861.8*	*1868.0*	*8525.0*	*0.0*	*0.0*
2021	*122.8*	*28861.8*	*1868.0*	*8525.0*	*0.0*	*0.0*
2022	*122.8*	*29369.0*	*1868.0*	*8525.0*	*0.0*	*0.0*
2023	*122.8*	*29369.0*	*1868.0*	*8525.0*	*0.0*	*0.0*
2024	*122.8*	*29369.0*	*1868.0*	*8525.0*	*0.0*	*0.0*
2025	*122.8*	*29369.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2026	*122.8*	*29369.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2027	*122.8*	*29369.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2028	*122.8*	*29369.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2029	*122.8*	*29369.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2030	*122.8*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2031	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2032	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2033	*0.0*	*32444.6*	*1868.0*	*8525.0*	*0.0*	*0.0*
2034	*0.0*	*33020.8*	*4496.9*	*8525.0*	*0.0*	*0.0*
2035	*0.0*	*33020.8*	*7505.1*	*8525.0*	*0.0*	*356.8*
2036	*0.0*	*33020.8*	*7505.1*	*8525.0*	*0.0*	*3907.5*
2037	*0.0*	*33020.8*	*11251.8*	*8525.0*	*0.0*	*3947.4*
2038	*0.0*	*33020.8*	*15291.7*	*8525.0*	*0.0*	*3947.4*
2039	*0.0*	*33020.8*	*19603.6*	*8525.0*	*0.0*	*3947.4*
2040	*0.0*	*33020.8*	*24207.4*	*8525.0*	*0.0*	*3947.4*

Table E11 – Annual power output (GWh) by technology in the Optimistic PV Roof-top scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar PV	Wind
2011	*122.8*	*12192.0*	*53.1*	*0.0*	*0.0*	*0.0*
2012	*122.8*	*12192.0*	*907.5*	*0.0*	*0.0*	*0.0*
2013	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2014	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2015	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2016	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2017	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2018	*122.8*	*19362.7*	*1868.0*	*0.0*	*0.0*	*0.0*
2019	*122.8*	*19362.7*	*1868.0*	*8525.0*	*0.0*	*0.0*
2020	*122.8*	*28861.9*	*1868.0*	*8525.0*	*0.0*	*0.0*
2021	*122.8*	*28861.9*	*1868.0*	*8525.0*	*0.0*	*0.0*
2022	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2023	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2024	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2025	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2026	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2027	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2028	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2029	*122.8*	*29369.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2030	*122.8*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2031	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2032	*0.0*	*32412.2*	*1850.0*	*8525.0*	*0.0*	*0.0*
2033	*0.0*	*32444.7*	*1868.0*	*8525.0*	*0.0*	*0.0*
2034	*0.0*	*33020.9*	*4497.0*	*8525.0*	*0.0*	*0.0*
2035	*0.0*	*33020.8*	*7505.0*	*8525.0*	*0.0*	*356.9*
2036	*0.0*	*33020.8*	*7505.0*	*8525.0*	*0.0*	*3907.5*
2037	*0.0*	*33020.8*	*11251.7*	*8525.0*	*0.0*	*3947.4*
2038	*0.0*	*33020.8*	*15291.7*	*8525.0*	*0.0*	*3947.4*
2039	*0.0*	*33020.8*	*19603.6*	*8525.0*	*1274.6*	*3947.4*
2040	*0.0*	*33020.8*	*24207.4*	*8525.0*	*2622.6*	*3947.4*

Table E12 – Annual power output (GWh) by technology in the Hydro-capital scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Solar PV	Wind
2011	*122.8*	*12192.0*	*53.1*	*0.0*	*0.0*	*0.0*
2012	*122.8*	*12192.0*	*907.5*	*0.0*	*0.0*	*0.0*
2013	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2014	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2015	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2016	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2017	*122.8*	*12192.0*	*1868.0*	*0.0*	*0.0*	*0.0*
2018	*122.8*	*19362.7*	*1868.0*	*0.0*	*0.0*	*0.0*
2019	*122.8*	*19362.7*	*1868.0*	*8525.0*	*0.0*	*0.0*
2020	*122.8*	*28861.9*	*1868.0*	*8525.0*	*0.0*	*0.0*
2021	*122.8*	*28861.9*	*1868.0*	*8525.0*	*0.0*	*0.0*
2022	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2023	*122.8*	*29369.1*	*1868.0*	*8525.0*	*0.0*	*0.0*
2024	*122.8*	*29972.0*	*1868.0*	*8525.0*	*0.0*	*0.0*
2025	*122.8*	*29972.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2026	*122.8*	*29972.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2027	*122.8*	*29972.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2028	*122.8*	*29972.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2029	*122.8*	*29972.0*	*1850.0*	*8525.0*	*0.0*	*0.0*
2030	*0.0*	*33015.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2031	*0.0*	*33015.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2032	*0.0*	*33015.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2033	*0.0*	*33015.1*	*1850.0*	*8525.0*	*0.0*	*0.0*
2034	*0.0*	*33020.8*	*1868.0*	*11153.9*	*0.0*	*0.0*
2035	*0.0*	*33020.9*	*1850.0*	*14536.9*	*0.0*	*0.0*
2036	*0.0*	*33020.9*	*1850.0*	*18087.5*	*0.0*	*0.0*
2037	*0.0*	*33020.8*	*1850.0*	*21874.1*	*0.0*	*0.0*
2038	*0.0*	*33020.8*	*1850.0*	*21966.7*	*0.0*	*3947.4*
2039	*0.0*	*33020.9*	*1850.0*	*26278.6*	*0.0*	*3947.4*
2040	*0.0*	*33020.9*	*1850.0*	*30882.4*	*0.0*	*3947.4*

Table E13 – Amortized costs (million USD) by technology in Optimistic PV roof-top scenario

Year	Diesel PP	Hydro PP	Gas PP	Coal PP	Wind PV	Total
2011	*35.54*	*430.66*	*44.38*	*0*	*0.00*	*510.58*
2012	*35.54*	*430.66*	*139.29*	*0*	*0.00*	*605.49*
2013	*35.54*	*430.66*	*195.43*	*0*	*0.00*	*661.63*
2014	*35.54*	*430.66*	*195.43*	*0*	*0.00*	*661.63*
2015	*35.54*	*430.66*	*195.43*	*0*	*0.00*	*661.63*
2016	*38.06*	*430.66*	*201.77*	*0*	*0.00*	*670.49*
2017	*38.06*	*662.94*	*201.77*	*0*	*0.00*	*902.77*
2018	*38.06*	*1022.58*	*201.77*	*326.12*	*0.00*	*1588.53*
2019	*38.06*	*1022.58*	*201.77*	*541.38*	*0.00*	*1803.79*
2020	*38.06*	*1036.92*	*201.77*	*541.38*	*0.00*	*1818.14*
2021	*40.59*	*1061.65*	*208.10*	*582.80*	*0.00*	*1893.15*
2022	*40.59*	*1062.42*	*208.10*	*582.80*	*0.00*	*1893.91*
2023	*40.59*	*1062.42*	*208.10*	*582.80*	*0.00*	*1893.91*
2024	*40.59*	*1062.42*	*208.10*	*582.80*	*0.00*	*1893.91*
2025	*40.59*	*1062.42*	*206.93*	*582.80*	*0.00*	*1892.74*
2026	*43.11*	*1062.42*	*213.20*	*624.22*	*0.00*	*1942.95*
2027	*43.11*	*1062.42*	*213.20*	*624.22*	*0.00*	*1942.95*
2028	*43.11*	*1062.42*	*213.20*	*624.22*	*0.00*	*1942.95*
2029	*43.11*	*1166.06*	*213.20*	*624.22*	*0.00*	*2046.59*
2030	*0.00*	*1170.65*	*213.20*	*624.22*	*0.00*	*2008.08*
2031	*0.00*	*1170.65*	*219.48*	*665.63*	*0.00*	*2055.77*
2032	*0.00*	*1172.98*	*219.48*	*665.63*	*0.00*	*2058.10*
2033	*0.00*	*1214.41*	*282.18*	*665.63*	*0.00*	*2162.22*
2034	*0.00*	*1215.28*	*543.00*	*665.63*	*27.44*	*2451.36*
2035	*0.00*	*1215.28*	*758.38*	*665.63*	*300.89*	*2940.19*
2036	*0.00*	*1215.28*	*835.09*	*707.05*	*308.40*	*3065.83*
2037	*0.00*	*1215.28*	*1186.63*	*707.05*	*308.45*	*3417.41*
2038	*0.00*	*1215.28*	*1565.23*	*707.05*	*308.45*	*3796.01*
2039	*0.00*	*1215.28*	*1969.33*	*707.05*	*308.45*	*4200.12*
2040	*0.00*	*1215.28*	*2350.63*	*707.05*	*308.45*	*4581.42*

Table E14 – Trajectory of electricity price in Optimistic reference scenario

Year	Amortized costs (million USD)	Power generation (GWh)	Electricity price (USD/kWh)
2011	*510.58*	*12367.8*	*0.041*
2012	*605.49*	*13222.2*	*0.046*
2013	*661.63*	*14182.7*	*0.047*
2014	*661.63*	*14182.7*	*0.047*
2015	*661.63*	*14182.7*	*0.047*
2016	*670.49*	*14182.7*	*0.047*
2017	*902.77*	*14182.7*	*0.064*
2018	*1588.53*	*21353.5*	*0.074*
2019	*1803.79*	*29878.5*	*0.060*
2020	*1818.14*	*39377.6*	*0.046*
2021	*1893.15*	*39377.6*	*0.048*
2022	*1893.91*	*39884.8*	*0.047*
2023	*1893.91*	*39884.8*	*0.047*
2024	*1893.91*	*39884.8*	*0.047*
2025	*1892.74*	*39866.8*	*0.047*
2026	*1942.95*	*39866.8*	*0.049*
2027	*1942.95*	*39866.8*	*0.049*
2028	*1942.95*	*39866.8*	*0.049*
2029	*2046.59*	*39866.8*	*0.051*
2030	*2008.08*	*42787.2*	*0.047*
2031	*2055.77*	*42787.2*	*0.048*
2032	*2058.10*	*42787.2*	*0.048*
2033	*2162.22*	*42837.6*	*0.050*
2034	*2451.36*	*46042.7*	*0.053*
2035	*2940.19*	*49407.7*	*0.060*
2036	*3065.83*	*52958.3*	*0.058*
2037	*3417.41*	*56744.9*	*0.060*
2038	*3796.01*	*60784.8*	*0.062*
2039	*4200.12*	*65096.8*	*0.065*
2040	*4581.42*	*69700.5*	*0.066*